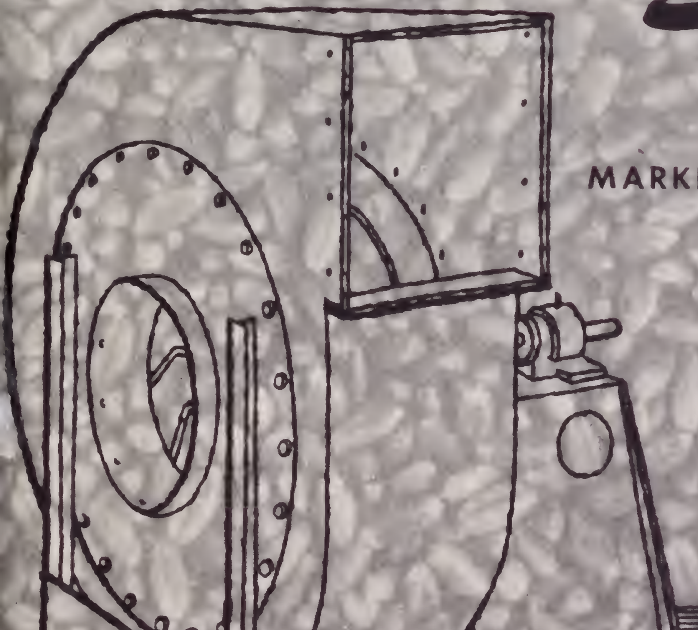
Aeration of GRAIN in Commercial Storages



MARKETING RESEARCH REPORT No. 178

Agricultural Marketing Service
Marketing Research Division
Washington 25, D.C.
in cooperation with
Agricultural Experiment Stations
of Georgia, Indiana, Iowa, Kansas,
Michigan, and Texas

UNITED STATES DEPARTMENT OF AGRICULTURE

PREFACE

This interim publication reports some of the preliminary findings of a broad research project covering the aeration of grain in commercial storage, which is being conducted in cooperation with the Agricultural Experiment Stations of Georgia, Indiana, Iowa, Kansas, Michigan, and Texas.

The material in this publication was prepared by the following agricultural engineers in the Handling and Facilities Research Section, Transportation and Facilities Branch, Marketing Research Division, Agricultural Marketing Service.

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Many grain storage operators made their facilities available for the testing of experimental and commercial aeration systems and also offered helpful suggestions and criticisms. Acknowledgement is also made to suppliers who loaned equipment for use in a number of the tests.

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IN COMMERCIAL STORAGE

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September 1957

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. - Price 35 cents

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AERATION OF GRAIN IN COMMERCIAL STORAGES

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SUMMARY

Many grain storage operators periodically "turn" stored grain—*move it through the air*—to help maintain market quality. Aeration systems using motor-driven fans to *move air through the stored grain* usually can do the job cheaper—and better. Aeration is applicable to all types of storages, but it is especially applicable to flat storages where it is difficult to move or turn the grain. In fact, without aeration longtime storage in flat structures is impractical. With aeration, market quality of the grain is maintained without moving the grain, and wear and tear on both the grain and handling machinery is reduced. Aeration systems are also effective and efficient in applying fumigants to grain while in storage.

The small amount of air used for aeration—about a quart per minute per bushel—is not costly to provide. Airflow rates ranging from 1/50 up to 1/4 cubic feet of air per minute (cfm) per bushel are suitable; the most commonly used rates are from 1/20 to 1/10 cfm per bushel.

The installed cost of aeration systems ranges from 1 to 5 cents per bushel capacity, depending on the size of the storage, the type of system, ease of installation, and other contributing factors. This cost can be prorated over a period of years. Normal operating (power) costs range from 1/10 to 1/2 cent per bushel per year. In comparison, power and labor costs for turning grain 4 times a year range from 1/2 to 1 1/2 cents per bushel for the 4 turns.

Aeration is usually accomplished by pulling outside air downward through the grain and exhausting it through the fan. In southern areas there may be some advantage in forcing the air upward through the grain; the heat trapped under the storage roof then is moved out without passing through the grain. There is little or no difference in power requirements and operating costs for pulling or pushing air through stored grain. Most fan assemblies can be changed on the aeration system to either pull or push air as the operator desires.

The fan horsepower required for aeration varies with the kind of grain, its stored depth, and the airflow rate per bushel. One horsepower will aerate up to 100,000 bushels of shelled corn 20 feet deep at 1/20 cfm per bushel. The same horsepower will aerate only about 5,000 bushels of wheat 100 feet deep at the same airflow rate.

Cooling clean grain having an initial temperature of 75° to 100° F., where considerable evaporative cooling takes place, requires from 1 to 2 days aeration time at 1/4 cfm per bushel; 3 to 4 days at 1/10 cfm per bushel; 6 to 8 days at 1/20 cfm per bushel; and 15 to 18 days at 1/50 cfm per bushel. Cooling grain having an initial temperature of 75° F. and below, where little evaporative cooling takes place, may require twice the aeration time given above. Total aeration time depends on the number of cooling stages.

It should not be assumed that aeration is an answer to all grain storage problems. Aeration may not completely eliminate all "turning" of stored grain but it should be considered in future grain storage programs. It can be an important practice in maintaining the market quality of stored grain and in minimizing handling costs.

BACKGROUND INFORMATION

Preservation of grain quality has always been a problem to the grain warehouseman. This problem has increased as stocks of grain have accumulated in commercial elevators including flat storage annexes, converted oil tanks, airplane hangars, and other emergency storages. The storage period also has been lengthened. Aeration is being successfully used by a number of commercial storage operators to help solve this enlarged storage problem.

Aeration systems are being used in commercial storage for such purposes as:

1. Cooling stored grain to prevent or minimize mold growth and insect activity.
2. Equalizing temperatures in stored grain to prevent moisture from moving from warm to cooler grain.

[1] This report was compiled from material prepared by agricultural engineers who are listed in the Preface.

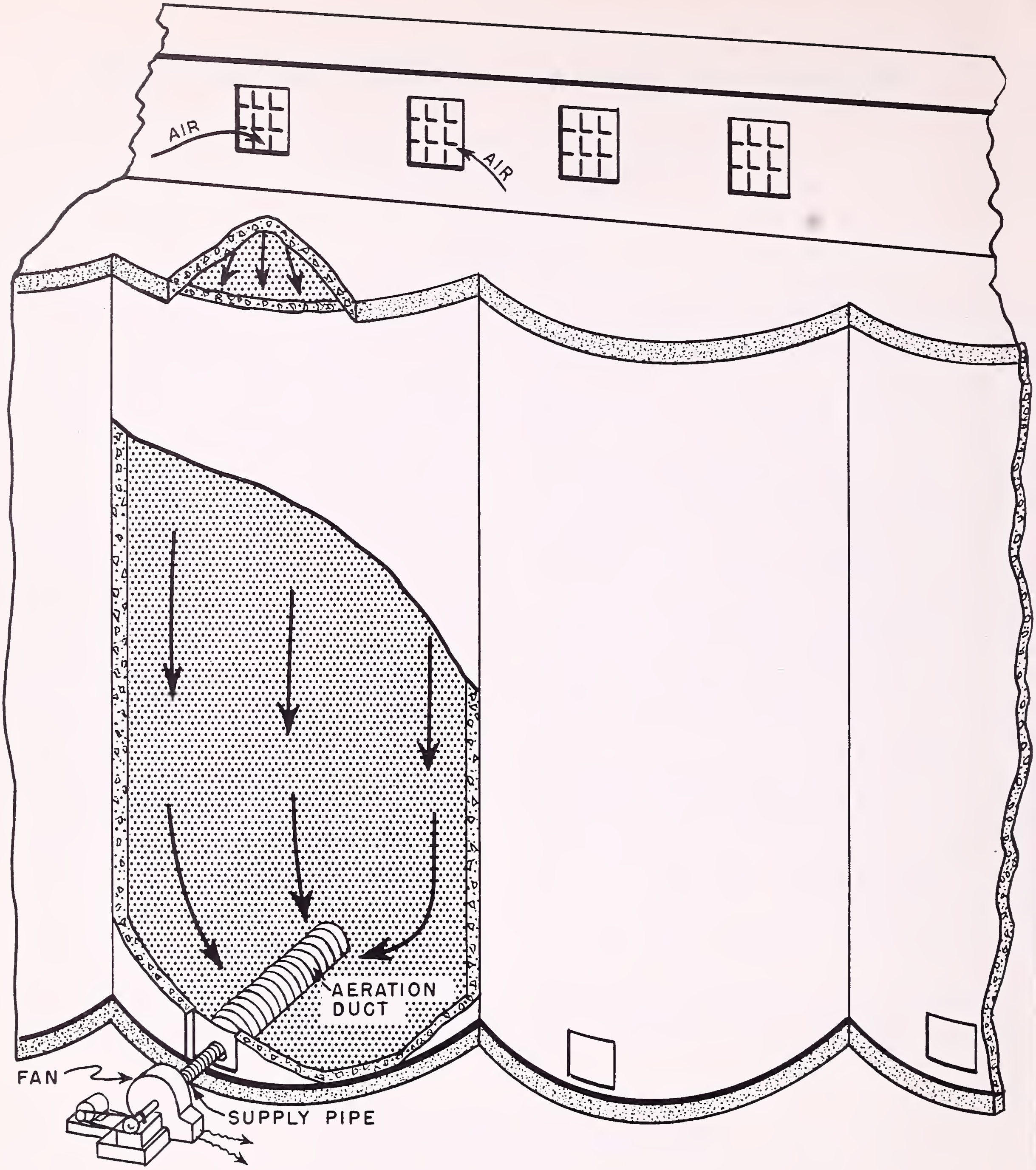

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FIGURE 1.—An aeration system with fan, aeration duct, and supply pipes installed in upright storage.

3. Removing odors from stored grain.
4. Applying fumigants to stored grain.
5. Holding moist grain in storage for brief periods.

Aeration may be helpful also in hastening moisture equalization of stored grain, in "blending" grain for certain milling purposes, and for conditioning cold grain before it is removed from storage. However, available information is inadequate to provide a basis for definite conclusions.

Methods other than aeration such as turning are more generally used in commercial storages to maintain the market quality of stored grain. Grain storage operators have long followed the practice of "turning" grain—*moving it through the air*—when it is stored for more than a few weeks. To turn grain, conveying equipment and empty storage space are needed. During turning operations, considerable grain breakage and shrinkage generally occurs. As grain is in motion through the air for only a short time, ordinarily 1 minute or less, repeated turnings are necessary to accomplish satisfactory cooling of warm grain. Both research results and industry experience have demonstrated that aeration can accomplish results that are equal to or better than turning, and at less cost.

In some storages, a blast of cooling air is moved through the grain while it is run through a drier. This method is more effective than turning but it still involves moving the grain.

High moisture and caked grain can be removed by topping, although this generally does not solve the moisture accumulation problem as new layers of caked grain are likely to form again. Also the grain surface can be stirred periodically but this is a costly and questionable measure for preventing surface spoilage. As a means of providing optimum storage conditions there is interest in airtight storage. However, there are currently economic, as well as operational, problems that have limited its use.

Aeration is not new to the grain trade. A patent was granted in 1935 on an apparatus for conditioning grain by aeration and for forced fumigation. Although several of these systems were installed in commercial elevators, they either were not designed in accordance with engineering principles of air movement or were not operated within proper limits and did not prove satisfactory.

Recent research results indicate that many of the mistakes of early aeration attempts have been corrected. Studies of aeration in Government-owned bins of corn underway since 1949 show good results. During the 3-year period 1952–55 in the reserve fleets of ships wheat was successfully stored without turning. In addition many commercial and farm installations have demonstrated that fans can be successfully used to move air through stored grain to maintain its market quality. Reportedly, aeration is also becoming a common practice in central Europe.[2]

PURPOSE

This publication covers: (1) The design, selection of equipment, and installation of grain aeration systems; (2) the operation of such systems; (3) ownership and operating costs; and (4) examples of installations.

One of its purposes is to provide information on the design, selection, and installation of aeration systems for use by commercial grain storage operators who are considering the installation of aeration equipment or modification of existing systems. This information also should be useful to design engineers, equipment suppliers, and others who may assist storage operators in designing, selecting, and installing equipment. The data on operating criteria should be of interest and value to those who now have aeration systems as well as those who plan to install such systems. The same is true of the material costs. Examples of installations are given to suggest steps that should be helpful to engineers and others in designing and installing aeration systems.

This publication is not intended to cover farm storage installations. However, some parts of the report may be of value to those interested in the storage of grain on farms.

DEFINITION OF TERMS

Terms generally familiar to the grain trade are not defined or explained. Certain terms which may be unfamiliar to some readers, and terms used in a special sense, are defined below:

Aeration.—The moving of air through stored grain at low airflow rates, for purposes other than drying, to maintain or improve its value.

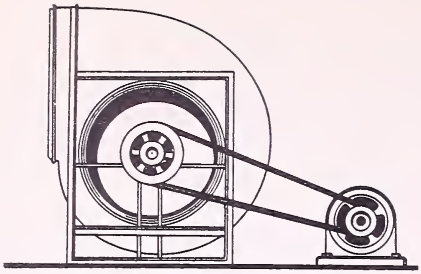
Aeration duct.—A chamber in the grain through which air is moved into or out of the grain. This chamber also is commonly referred to as a collector, tunnel, air duct, plenum chamber, etc.

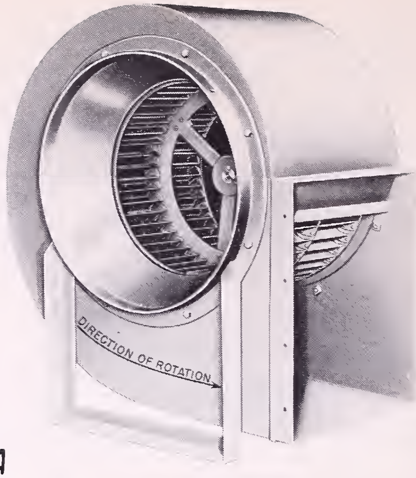
Supply pipe.—A tight-walled pipe or tube for conveying air between the fan and aeration duct.

cfm.—An abbreviation used in expressing "cubic feet of air per minute," the designation for the volume of air being moved.

Static pressure (S. P.).—A measure of the force or pressure that must be exerted on air to move it through grain and the aeration system. It is used in determining fan and horsepower requirements and in fan ratings furnished by fan manufacturers. Static pressure usually is measured in inches of water. See Appendix.

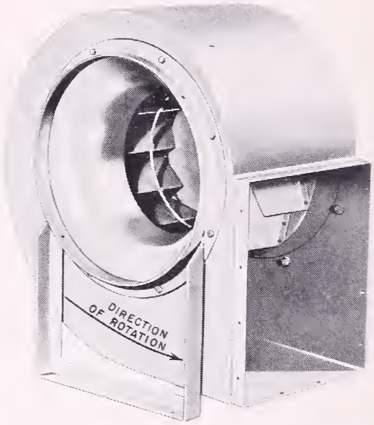
[2] Theimer, O. F. Ventilation of Grain Storages. Agr. Engin., vol. 32, No. 2, Feb. 1951.





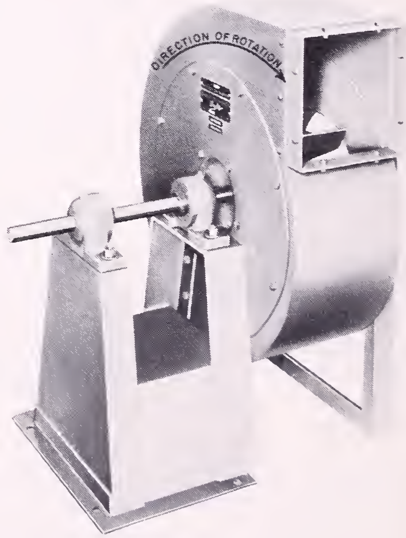
A

Figure 2.—Centrifugal fan consisting of a fan rotor or wheel within a scroll type of housing. It is designed to move air over a wide range of volumes and pressures (up to 15 inches of water and above). The fan wheel may be equipped with radial tip blades or three other types.



B

A. Fan wheel equipped with forward curve tip blade.



C

B. Fan wheel equipped with backward curve tip blade.

C. Fan wheel equipped with straight tip blade.

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Upright storage.—Any storage where the height is greater than the diameter or width. This type of storage also is commonly referred to as a deep bin, tank, silo, cell, or vertical storage.

Flat storage.—Any storage where the height is less than the diameter or width. These storages also are referred to as horizontal storages.

Grain.—All cereal grains, oil seeds, and other seeds unless otherwise designated.

Cooling zone.—That portion of the grain mass in a storage where the temperature is falling during aeration.

Cooling stage.—The time required to move a cooling zone entirely through a lot of stored grain.

DESIGN, SELECTION OF EQUIPMENT, AND INSTALLATION OF AERATION SYSTEMS

The principal parts of an aeration system and their functions are: (1) One or more fans to supply the necessary air at the required static pressure; (2) aeration ducts to move air into or out of the stored grain; (3) supply pipes to connect the fans and aeration ducts; (4) a motor to operate each fan; (5) controls to regulate the operation of the fan; and (6) the storage in which the system is installed (fig. 1).

Before designing a system and selecting aeration equipment, the operator should consider: (1) What types of grains are to be aerated; (2) the kinds of storage structures in which the system is to be installed; (3) the airflow rate per unit (bushel, barrel, etc.) to be provided; and (4) the number of storages or the quantity of grain to be serviced by each fan. After these points have been considered determinations should be made as to: (1) Total air volume to be supplied; (2) the static pressure against which the fan must operate; (3) size and type of fan and motor needed; and (4) the kinds of aeration ducts and supply pipes needed. The following information on airflow, fan, duct, and power requirements is provided to help in making these determinations.

AIRFLOW REQUIREMENTS

Airflow rates suitable for the aeration of grain are given in table 1. These rates are based on experience and on the results of completed tests. They may be modified as additional data become available covering wider ranges of conditions. For example, it appears that aeration rates for pea beans in the Michigan area should be 1/10 cfm per bushel for upright storages and 1/10 to 1/5 cfm for flat storages. Also there may be exceptions for other special crops.

FAN REQUIREMENTS

The selection of a fan for aeration depends on: (1) Volume of air to be delivered; and (2) the static pressure at which the fan must operate to move the air through the grain and aeration system. Static pressure will vary with airflow rate; depth of grain; kind, size, and condition of grain; and the resistance of the aeration system.

TABLE 1.—*Airflow rates for aeration of stored grain in specified areas* [1]

Type of storage	Airflow rate per bushel of grain [2]	
	Northern States	Southern States
	cfm	*cfm*
Flat	1/20 to 1/10	1/20 to 1/4
Upright	1/40 to 1/20	1/20 to 1/10
Farm	[3] 1/20 to 1/10	1/20 to 1/4

[1] Except as otherwise specified, rates are based on intermittent fan operation when air conditions are suitable.

[2] Bushel equals 1.25 cubic feet; barrel equals 4.5 cubic feet or 3.6 bushels.

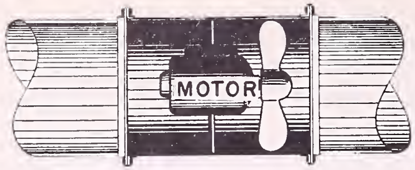
[3] For continuous operation, 1/60 to 1/30 cfm per bushel.

Kernel size, moisture content, and the amount of foreign material in grain affect the resistance of grain to airflow. For example, the resistance to airflow of alfalfa seed is much higher than that of shelled corn or soybeans. Also the resistance of wheat is greater than that of rough rice or grain sorghum and several times that of shelled corn. To illustrate, in moving 1/10 cfm per bushel through 100 feet of shelled corn the static pressure would be about 7½ inches of water.[3] In comparison, to obtain the same airflow rate through 100 feet of wheat, the static pressure would be over 25 inches of water or more than 3 times as great as that for corn.

The resistance of most grains to airflow increases almost directly in proportion to the depth. Varying the airflow rate for any grain also affects the static pressure and power required (table 2).

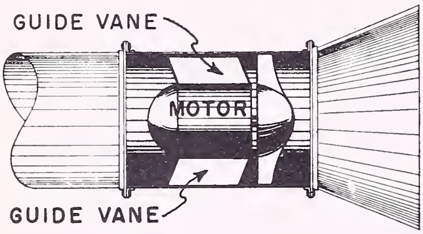
Most aeration systems in use in upright storages in 1956 were designed for static pressures not exceeding 15 inches of water. However, systems operating at static pressures of 10 inches or less were more common.

[3] The static pressure being developed by the fan in moving the air indicated is equivalent to the pressure that will lift a column of water 7½ inches.



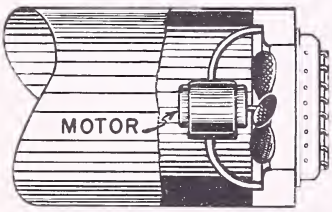
A. TUBEAXIAL FAN

A tubeaxial fan consists of an axial flow wheel within a cylinder. It is designed to move air through a wide range of volume at low to medium static pressures.



B. VANEAXIAL FAN

A vaneaxial fan consists of an axial flow wheel within a cylinder combined with a set of air guide vanes located either before or after the wheel. It is designed to move air over a wide range of volume and pressures.



C. PROPELLER FAN

A propeller fan consists of an axial flow fan within a mounting ring or plate. It is designed to move air over a wide range of volume at low static pressures.

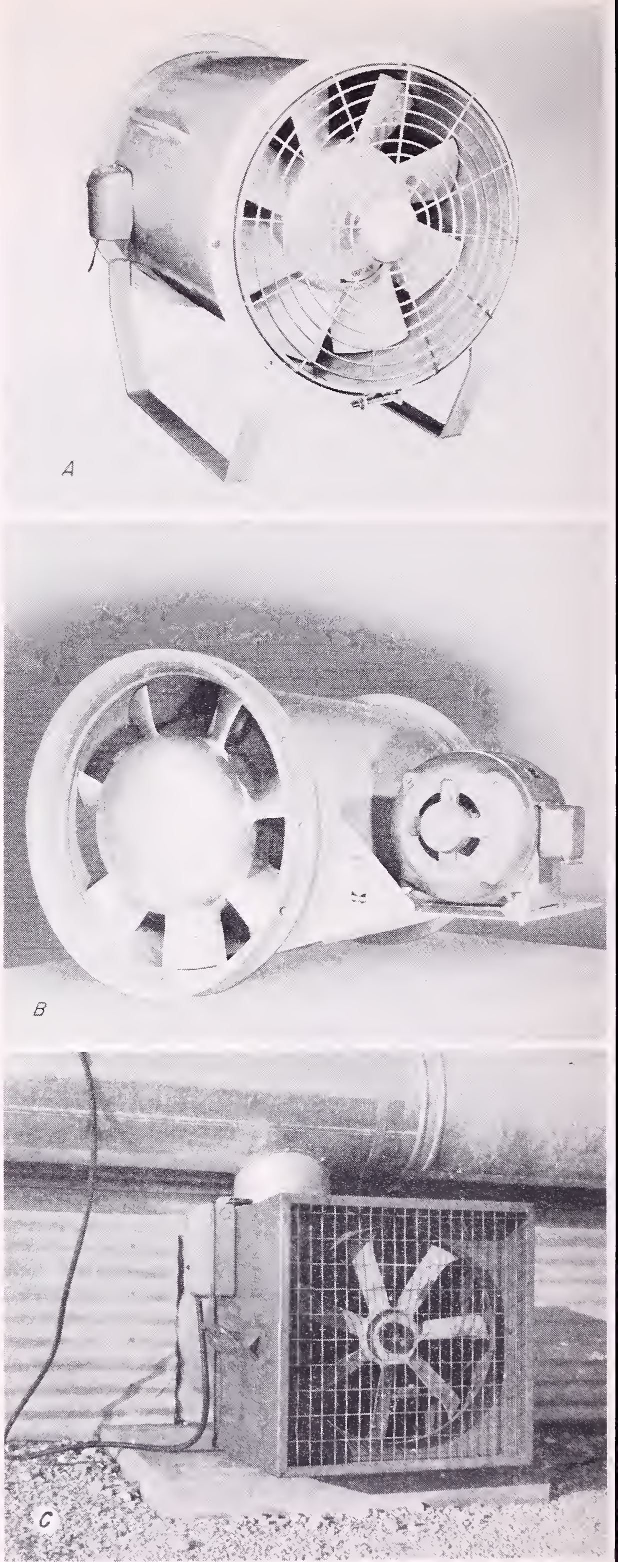


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FIGURE 3.—Axial flow fans.

TABLE 2.—*Resistance of wheat and aeration system to airflow at specified rates of flow when wheat is stored in a bin 18 feet in diameter and 100 feet deep*

Airflow rate (cfm./bu.)	Static pressure	Power requirements for fan
	Inches water	*Horsepower*
1/10	26. 0	17. 5
1/20	12. 4	4. 2
1/30	7. 8	1. 8

TYPES OF FANS

Both axial flow (propeller) and radial flow (centrifugal) fans are used for aeration. Either type is used where the static pressure of the grain and the system are not more than 5 or 6 inches of water. Centrifugal fans are commonly used for higher pressures. In 1956 propeller fans were generally used in flat storages and centrifugal fans in upright storages.

Three types of centrifugal fans are shown in figure 2. The "forward-curve" fan, figure 2–A, has a large number of blades and operates at a relatively slow speed. One objection to this fan is that the motor may be overloaded if the static pressure is decreased so the fan delivers additional air. Air conditioning or furnace fans are not satisfactory for aeration systems.

A centrifugal fan with straight blades, figure 2–C, is often referred to as a pressure fan, industrial exhauster, or material handling fan. This type of fan is widely used in aerating grain in upright storages. It also overloads when the static pressure is reduced but not as much as a forward curve fan.

A "backward-curve" centrifugal fan, figure 2–B, has about 12 blades and is a high-speed fan. It is slightly more efficient, but more expensive, than a forward-curve or straight-blade fan. It has a self-limiting horsepower characteristic. If the motor size is adequate for fan operation near the point of greatest efficiency there will be no danger of an overload.

Three types of axial flow fans are shown in figure 3. While essentially considered as low pressure fans, certain designs have been used for the higher pressures. Axial flow fans are used in grain aeration systems but usually where static pressures do not exceed 5 or 6 inches of water.

Fans should be selected on the basis of performance ratings supplied by the manufacturer. A performance rating specifies the volume of air delivered by the fan over a range of static pressures. Reliable performance ratings are assured if the fans selected are rated in accordance with the testing code of the National Association of Fan Manufacturers.

FAN ARRANGEMENTS

Individual.—An individual fan for each storage or for each aeration duct in a storage is simple, versatile, and efficient (fig. 4). Aeration can be provided for each storage or aeration duct without regard to other systems. However, this system generally is more expensive since several small fans and motors cost more than a single fan and motor delivering the same total volume of air. The cost of electric wiring will also be greater. Another disadvantage is that the fumigant must be introduced into each tank individually.

Multiple.—A large fan can be connected to several storages or aeration ducts with connecting supply pipes (fig. 5). This hook-up should cost less per storage than the individual hook-up, and is more convenient because several storages can be aerated by actuating a single switch. Gate valves can be installed in the supply pipes so that the entire aeration system need not be operated as a unit. However, such installations result in the inefficient use of a relatively large fan and motor, and air usually escapes around the gate valves. There is also a higher friction loss in the supply pipe, which reduces the efficiency of the system. A recirculation system for distributing fumigant usually can be added to this system. Fumigant can be introduced into several storages simultaneously.

Portable.—A single portable fan can be used to aerate several storages or parts of storages at a reduction in the cost of equipment (fig. 6). However, this arrangement is inconvenient in that the one fan will have to be moved about frequently. There is also a limit on the number of storage units that can be aerated effectively by one fan. Some of the benefits of aeration may be lost in the last bins aerated.

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FIGURE 4.—Individual aeration system on upright storages with hopper bottoms.

A

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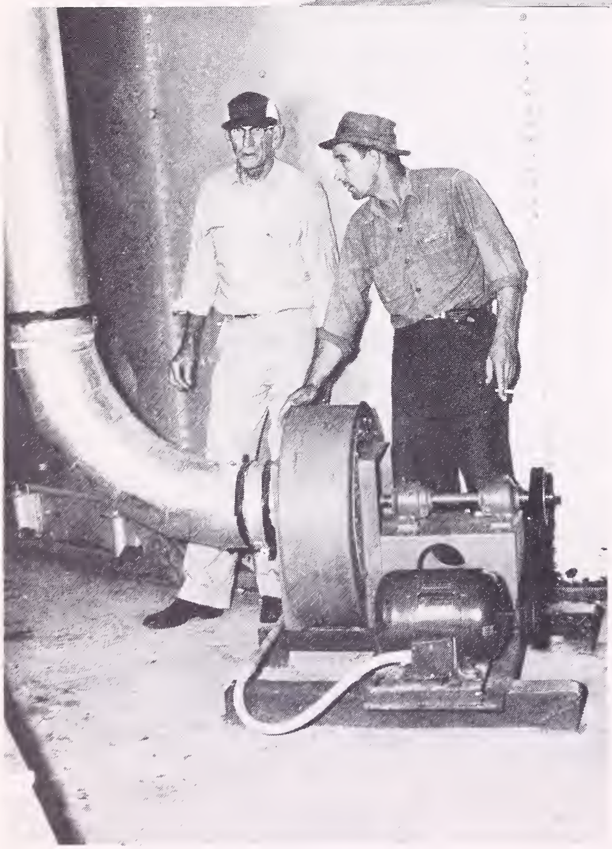

B

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Figure 5.—(A) Multiple aeration system with fan connected to several storages by connecting supply pipes. (B) Closeup of fan.

AERATION DUCTS

Aeration ducts are generally installed on the floor of the grain storage. They usually are uniform in size along their entire length. Ducts may be circular, semi-circular, arched, rectangular, or of an inverted V-shape or U-shape. Although perforated false floors theoretically are perfect air ducts, they are not commonly used for aeration because of their relatively high cost. Other less costly ducts, which permit some non-uniformity of airflow, have proven satisfactory.

Perforated ducts have air openings or perforations uniformly spaced over their surfaces to permit passage of air through the duct surface. The area of the perforations should equal at least 10 percent of the total duct surface area.

Each opening must be small enough to exclude the grain that is to be aerated. For example, round holes 3/32 inch in diameter or slots 5/64 inch wide will not pass normal-sized kernels of wheat. Larger openings may be used for shelled corn, soybeans, and other larger seeds. Although broken kernels and dockage may fall into the duct, this is not much of a problem.

Perforated ducts are commonly made of punched or expanded metal. A steel frame covered with expanded metal which in turn is covered with screen wire is also used. Screen wire for this purpose is not considered a permanent material but it is easily replaced when the storage is empty.

Tight-wall ducts of metal or wood with one side open, and facing downward, are also used as aeration ducts. The inverted V is one of the simpler shapes.

There is considerable interest in a "cross-flow" system for upright storages where aeration ducts would be installed vertically against the inside walls. This arrangement would provide a relatively short path for the flow of air in upright storages, and permit higher airflow rates at the same power requirements for a system where aeration ducts are installed on the floor. Currently there is no factual information available on a "cross-flow system" but research is underway.

DUCT CROSS-SECTIONAL AREA

The required size or cross-sectional area of the duct is governed by the amount of air the duct is to carry and by its length. Uneven distribution of air has been reported in flat storages where the maximum air velocities within the duct exceeded 1,500 feet per minute. The problem is more pronounced in long ducts and in ducts with rough or irregular surfaces. Further observations and more research are in progress on this problem.

Following is a list of recommended maximum air velocities within aeration ducts of varying lengths, including ducts with interior supports or framing and wire and mesh covering.

Duct length (feet)	*Air velocity within duct (feet per minute)*
5 to 25	2,000
25 to 60	1,500
60 to 100	1,000

The required cross-sectional area of aeration ducts can be determined from the above data if the total air volume and duct length are known. The total air volume divided by the maximum air velocity equals the minimum cross-sectional area.

$$\frac{\text{total air volume (cfm)}}{\text{air velocity (fpm)}} = \text{cross-section area (sq. ft.)}.$$

DUCT SURFACE AREA

Limiting the velocity of the air entering (or leaving) the grain surrounding the aeration duct prevents excessive pressure losses in this area. This velocity is influenced by the amount of surface area provided in the aeration duct and the airflow rate used.

With a semi-circular perforated duct the air enters or leaves the grain over the entire surface area. Therefore the entire duct surface can be included in determining the amount of surface area needed to hold static pressures to a desirable minimum (fig. 7). However, some modification is needed where a circular perforated duct rests on the floor or against a wall. Then only 80 percent of the surface area should be considered.

With a tight-wall aeration duct, air enters or leaves the grain only through the open side. Therefore only the area of the open side can be included in determining the amount of surface area needed (fig. 7).

Suitable duct surface areas for both upright and flat storages are discussed in the next two sections.

DUCTS FOR UPRIGHT STORAGES

The grain load on aeration ducts may reach 1,500 pounds per square foot in common upright storages. The duct also must withstand an additional drawoff load caused by the movement of grain during unloading. This drawoff load may be several times the static grain load and must be carefully considered in selecting ducts for hopper bottom bins. Duct anchoring is also a major consideration.

A single aeration duct, of the type shown in figure 8, frequently is used in upright storages. Ducts extending across a large part of the bin diameter are desirable. A 2-foot clearance from the edge of the bin drawoff should be maintained. Other typical duct layouts for upright storages are shown in figure 9.

A circular duct offers the greatest strength per unit weight of material. Galvanized or black iron sheet metal from 14- to 12-gage can be perforated and formed into grain tight smooth or corrugated

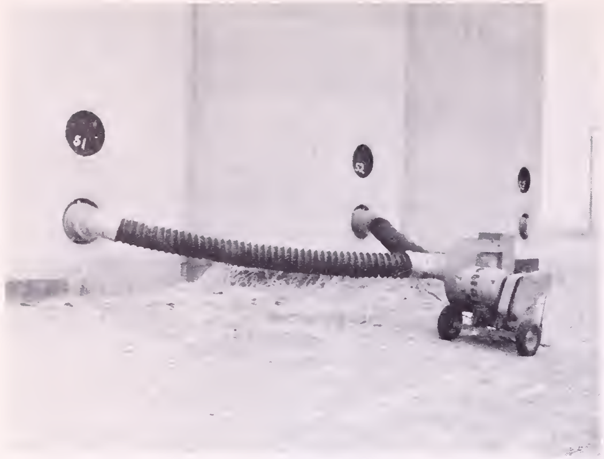

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FIGURE 6.—Portable fan and motor used to aerate 2 storages at one time. Fan is moved to adjoining storages when aeration is complete. The number of storages that can be satisfactorily aerated with a portable fan is limited. Molding of warm grain or moisture migration may take place in some bins before aeration is completed in other bins.

sections. Many concrete storages have small service entrances which can be used for installing prefabricated ducts up to about 18 inches in diameter. Larger ducts can be fabricated in parts and assembled inside the bin. Structural steel, strap iron, and steel braces are used to fasten the ducts to the bin floor and walls with rivets, power driven fasteners, expansion bolts, steel bolts, or a combination of other fasteners (fig. 10).

Semi-circular and arch-shaped ducts, with one flat side, have a larger base area for anchoring. Perforated sheet metal, 14-gage, is used by corrugating or supporting on frames and then by welding the duct to a base of strap iron or angle iron (fig. 11).

In some cases inverted "V" ducts are made from structural steel with sufficient strength to bridge a drawoff zone in the bin. In this case, it may be necessary to cover the open bottom side with screen wire especially if the duct is not placed in a horizontal position. Adequate support, anchoring, and duct strength may be problems in this type of installation.

Other types of ducts include those installed laterally from a solid main duct; those installed

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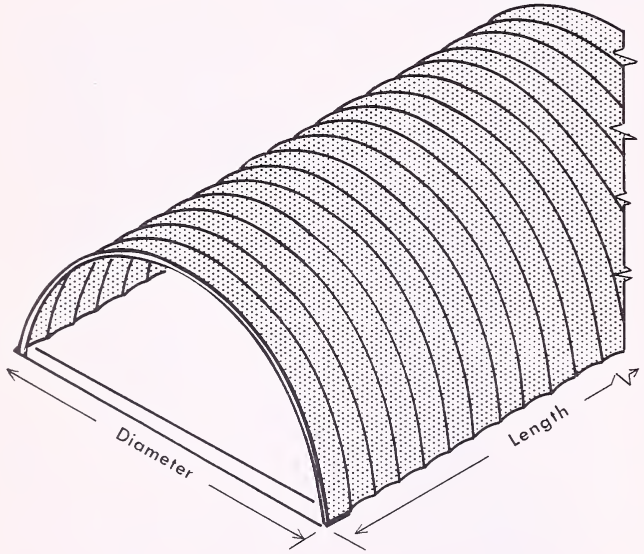
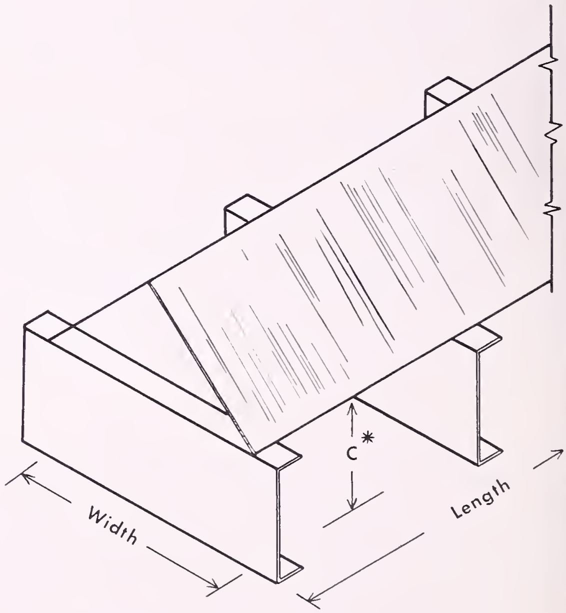


Semi-circular perforated corrugated duct with air openings spaced uniformly over the surface.

Duct surface area equals:
Semicircular duct—½ diameter x length x 3.14
Circular duct—diameter x length x 3.14

Note: An additional 20 to 25 percent of duct surface area should be provided where a circular perforated duct rests against a bin wall or floor.



Metal Tight-wall duct with one open side.

Duct surface area equals width x length

*Height "C" above bin floor must be equal to *at least* ½ of the duct width.

FIGURE 7.—Aeration duct surface area.

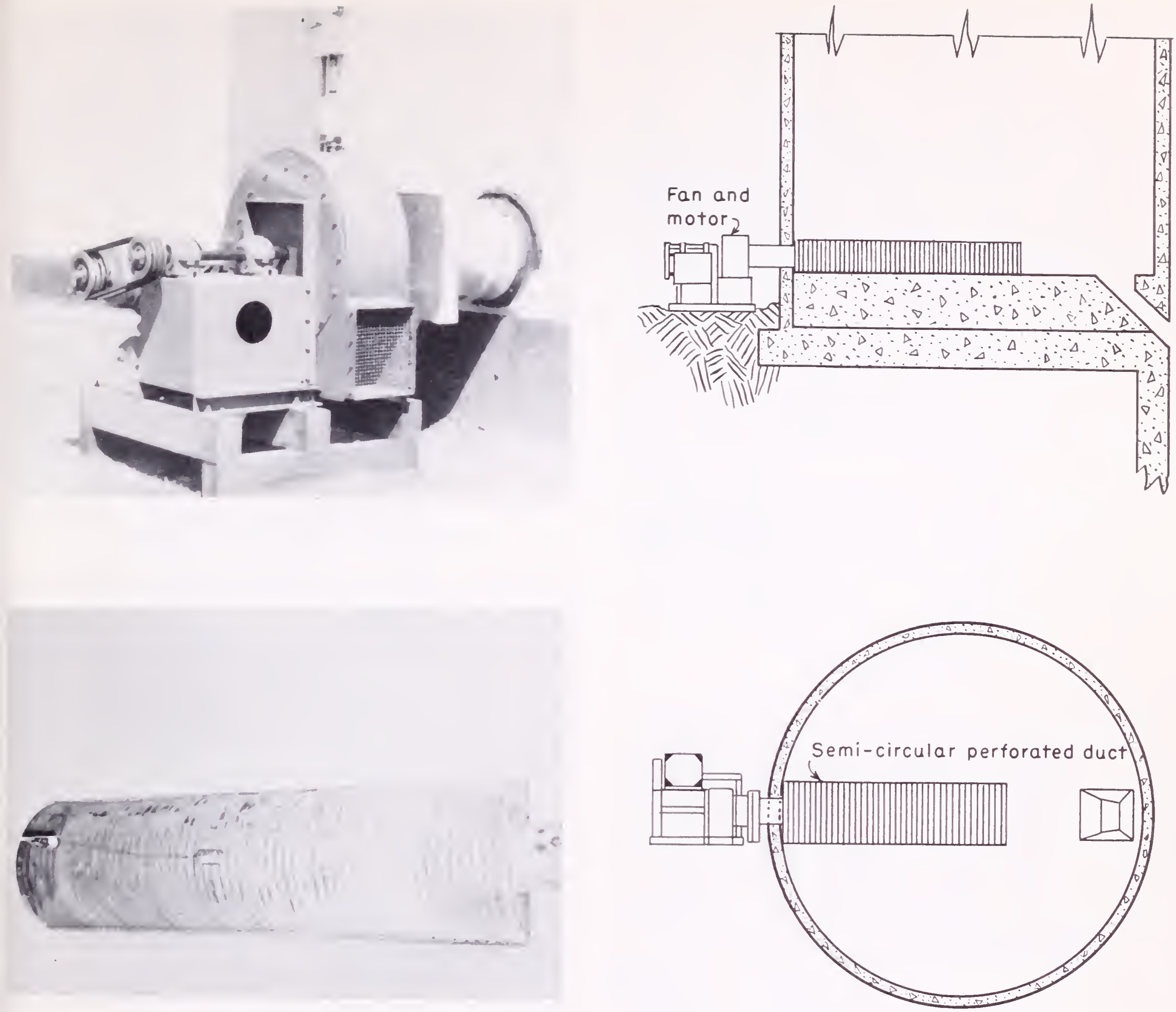


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FIGURE 8.—Aeration system for upright storage with flat bottom. A single aeration duct is shown.

radially from a central plenum chamber; and perforated ducts installed vertically.

The *partial hopper* (fig. 12) is used extensively in rice storages and has proven satisfactory. It has the advantage of being relatively inexpensive to install, and, if properly installed, has adequate structural strength. In some upright storages, adequate area for the air to leave (or enter) the grain cannot be provided, although this can sometimes be rectified by perforating the partial hopper.

Duct surface area.—The surface area of aeration ducts for upright storages may be the controlling factor in determining their size. Ducts for such storages have been designed for air velocities as high as 50 feet per minute (fpm) for the air entering or leaving the grain around the duct. However, a lower velocity of around 30 fpm is desirable if the additional cost of purchasing and anchoring the larger ducts is not prohibitive. Less power will be required at the lower air velocities. Over several years this saving in power often will justify the installation of larger ducts with greater surface area.

The total square feet of duct surface area required can be determined by *dividing* the total volume of air handled in each duct *by* the selected air velocity (fpm) for the duct surface area (30 to 50 fpm).

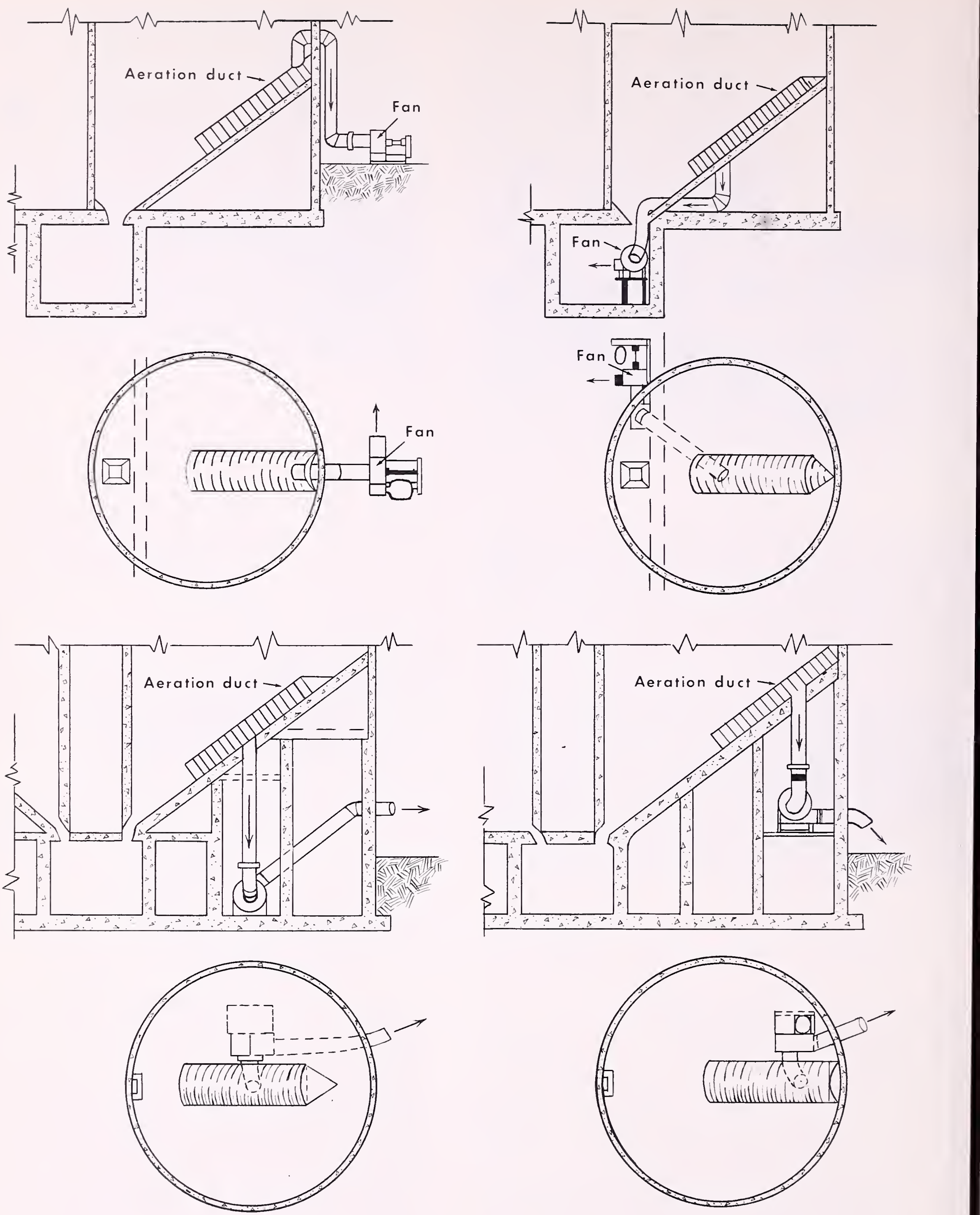

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FIGURE 9.—Typical aeration system layout for upright storages with hopper bottoms.

For example, if an aeration duct handles 1,200 cfm and the selected velocity is 30 feet per minute, the total square feet of *surface area* equals, $\frac{1{,}200 \text{ cfm}}{30 \text{ fpm}}=40$ square feet of surface area. Thus a perforated semicircular duct 16 feet long requires 2½ square feet of surface area per foot length of duct $\left(\frac{40}{16}=2\frac{1}{2} \text{ feet; } 2\frac{1}{2} \text{ x } 1 \text{ foot}=2\frac{1}{2} \text{ square feet per foot of length}\right)$. A perforated semi-circular duct 20 inches across the base and 10 inches in radius would meet these requirements. For the same airflow, a tight-wall duct 16 feet long with equivalent cross section area should have an open bottom side 2½ feet wide. Also the lower side of this duct should be at least 1¼ feet above the floor (one-half of the duct width). See figure 7 for illustrations of a perforated and a tight-wall aeration duct.

DUCTS FOR FLAT STORAGES

Common shapes and construction of aeration ducts used in flat storages are shown in figures 13–16. A satisfactory type of "home-built" duct (fig. 13) is made of concrete blocks and wood plank and can be varied in size to meet a wide range of conditions. If necessary, the duct can be dismantled and rebuilt each time the storage is emptied and refilled. The ducts described for use in upright storages can also be used in flat storages if properly sized.

Duct surface area.—The surface area may not be the controlling factor in designing aeration ducts for flat storages as it is for upright storages. The quantity of grain served per unit length of duct is usually smaller in flat storages. However, both the surface and the cross-sectional areas must be checked against the minimum requirements. The surface area of the longer perforated ducts will be adequate if the cross-sectional area is adequate. However, for ducts under 50 feet in length, the surface area requirement may control the size.

For common aeration airflow rates the total static pressure in flat storage is less than that in upright storages. Therefore, a relatively high static pressure in the grain surrounding the duct represents a higher percentage of the total static pressure. Consequently, it is desirable to design the ducts so that air velocities for the duct surface are limited to 20 to 30 feet per minute.

The total square feet of duct surface area required can be determined by *dividing* the total volume of air handled by each duct *by* the selected air velocity (fpm) for the duct surface area. For example, if an aeration duct handles 2,000 cfm and the selected velocity is 20 feet per minute, the total square feet of *surface area*, $\frac{2{,}000 \text{ cfm}}{20 \text{ fpm}}=100$ square feet of surface area. Thus, a duct 25 feet long requires 4 square feet of surface area per foot length of duct $\left(\frac{100}{25} \text{x } 1 \text{ foot}=4 \text{ square feet}\right)$. A perforated circular duct 16 inches in diameter, or other type of ducts having similar cross-sectional and surface areas, would meet these requirements. See figure 7 for illustrations of a perforated and a tight-wall aeration duct.

Duct spacing and layout.—In flat storages he duct spacing is related to the building dimensions. Prefabricated flat storages usually come in widths of 30 to 60 feet. In storages up to 40 feet in width, one duct is placed down the center of the building. In storages over 40 feet wide, 2 or more ducts are used. They are spaced so that the distance between the ducts is not greater than the grain depth. Ducts also may be placed crosswise in the building if the grain depth is relatively uniform.

In buildings up to about 100 feet in length, the fan usually is attached at one end of the duct. In longer storages the fan may be placed on one side of the building, or 2 fans used—one at each end of the building. A supply pipe is used between the fan and the aeration duct.

SUPPLY PIPES

Supply pipes provide for movement of air between the aeration duct and fan. They are usually round, smooth sheet metal pipe. They should be well supported and anchored.

Round pipe up to 15-inch diameter generally is of 20-gage metal, and 15- to 30-inch diameter pipe of 18-gage metal. If they are rectangular, heavier gages or additional bracing is required. Supply pipes may be installed through existing service entrances, through prepared openings in walls or floors, or through sleeving in walls or floors during new construction.

A maximum air velocity of 2,500 fpm is permissible for supply pipes but 1,500 to 2,000 is preferred. If elbows are used, they should have, wherever possible, an inside or throat radius of 2 pipe diameters. Abrupt changes in pipe diameter should be avoided.

Where the fan is attached to the aeration duct at the building wall, special fittings are required. Normally a special panel is provided for connecting the fan to the aeration duct through the building wall. The opening through the wall should not be smaller than the duct and perferably as large as the fan opening. If prefabricated panels are not available, the opening must be made both grain-tight and water-tight.

Where the fan is mounted at the side of a building, supply pipes can be used to connect the aeration ducts to the fan. The supply pipe should not be smaller in cross-sectional area than the total area of all the aeration ducts served.

There should be some provision for closing the fan end of the system after aeration is completed.

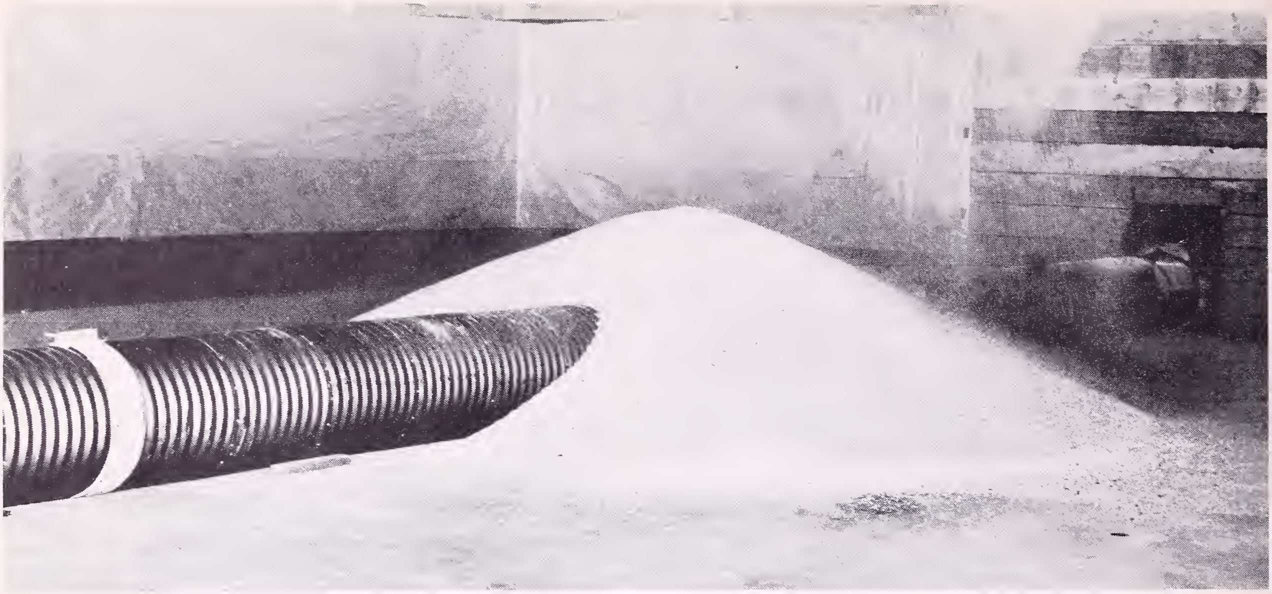

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FIGURE 10.—Circular perforated and corrugated steel aeration duct. Upright storages require 14- to 16-gage steel and flat storages 16- to 20-gage steel.

This can be accomplished by equipping the supply pipe from each bin with a slide gate, damper, or tight cap.

ESTIMATING FAN HORSEPOWER AND STATIC PRESSURE REQUIREMENTS FOR AERATING GRAIN

Figures 17 to 22 inclusive provide information for estimating the fan horsepower and static pressure requirements for aerating grain of various kinds, at different rates of airflow (cfm per bushel or barrel), and at depths ranging from 10 to 150 feet. Static pressures were calculated from those reported by Shedd for loose grain.[4] To make allowances for packed fill the values given by Shedd have been increased as follows: Wheat, shelled corn, and rice 30 percent; grain sorghum and pea beans 40 percent; and oats 50 percent. Shedd's values were also increased by 20 percent (with a minimum of 0.25 inch) for pressure losses in and around the aeration duct and in the supply pipes.

Fan horsepower requirements were calculated as follows:

$$\text{Fan horsepower} = \frac{\text{cfm x static pressure (inches of water)}}{3{,}000}$$

A static efficiency of 47 percent was assumed in calculating fan horsepower requirements. This is lower than the maximum efficiency listed for most fans. However, it is recognized that fans will not always operate at their highest efficiency. The method of fan installation, changes in the kinds and conditions of grain, and the overfilling and underfilling of bins will affect the fan efficiency. There also is a difference in fans. Some fans have a higher efficiency than others and will deliver more air per horsepower.

[4] Shedd, C. K., Resistance of Grains and Seeds to Airflow. Agr. Engin. 34:616–619. 1953.

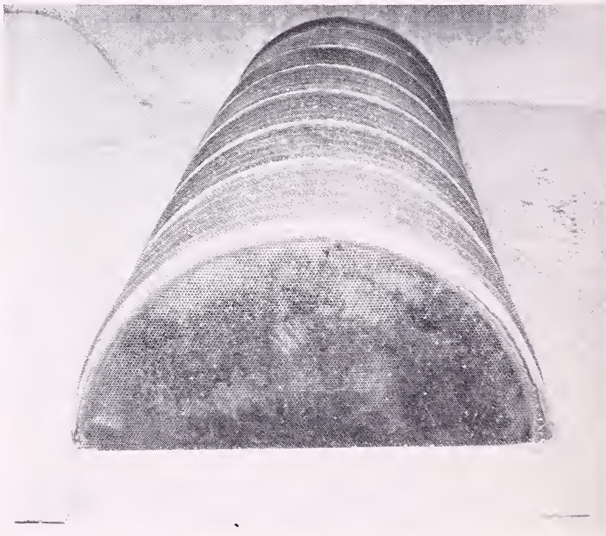

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FIGURE 11.—Semi-circular perforated and corrugated steel aeration duct. Steel base plates on each side of the duct anchor the duct to the storage. The end plate provides support for each end of the duct. Upright storages require 14-gage steel with steel arch supports inside of the duct. Flat storages require 16- to 20-gage steel.

The following information is supplied to use with the charts.

1. Kinds of grain to be aerated. An aeration system may be installed to aerate more than one kind of grain. Then a fan should be selected that will supply the desired airflow for the grain showing the highest static pressure. For example, if shelled corn and wheat are to be aerated, the fan should be selected for wheat (grain showing the higher static pressure of the two grains). If the fan selected is completely "non-overloading" the motor selection can be made on the same basis. However, some types of fans suitable for aerating grain will "overload" when static pressures are reduced. Where this type of fan is used to aerate more than one kind of grain some provision must be made to prevent overloading of the motor.

   One suggested method for selecting the motor size is to determine, for the same grain depth, the horsepower required to move air through the grain showing the lowest resistance to airflow at the *same static pressure* as the grain showing the highest resistance. A motor selected on this basis would be large enough to prevent overloading. Also, modification of aeration equipment will not be needed when changing from one grain to another. It is likely that the additional initial cost of a larger motor would not be more than the cost of other methods of control. The larger motor would use electric current in proportion to the operating load. An example of this method of selecting fan and motor size is given below.

   There are other satisfactory methods for preventing overloading of motors. The fan speed can be slowed to reduce the air volume by changing the pulley or sheave size on the motor or fan. Dampers can be placed in the fan inlet or outlet to reduce the air volume. These two methods require considerable attention to make sure that adjustments are always made when changing from one grain to another.
2. Volume of grain in barrels or bushels.
3. Depth, in feet, of storage or maximum depth of grain.
4. Airflow rate in cfm per bushel or barrel. Reference to the various charts will indicate the comparative power and static pressure requirements for the aerating of different grains at the same airflow rate.
5. Total volume of air needed (volume of grain in barrels or bushels x airflow rate in cfm per bushel or barrel).

An example of how to use the charts to determine fan and motor requirements. An aeration system to be designed for aerating either wheat or shelled corn in a storage 80 feet deep (capacity 28,800 bushels):

1. For wheat to be aerated at $\frac{1}{20}$ cfm per bushel use the chart in figure 18.
   a. Find 80 feet at bottom of chart.
   b. Follow vertical line to $\frac{1}{20}$ cfm curve.
   c. Read static pressure on broken line curving downward to right, in this case about *7.5 inches of water.*
   d. Total air volume for wheat$=28{,}800 \times \frac{1}{20}=$ 1,440 cfm.
2. For shelled corn use the chart in figure 17.
   a. Find 80 feet at bottom of chart.
   b. Follow vertical line to static pressure reading of 7.5 inches of water (from 1c above) (about 0.15 cfm per bushel).
   c. Follow horizontal line to left edge of chart. Read fan horsepower required per 1,000 bushels, in this case *0.38 horsepower.*
   d. Total power required =

$$\frac{28{,}800}{1{,}000} \times 0.38 = 10.9 \text{ horsepower.}$$

   It should be emphasized that horsepower calculations in these charts are based on a fan static efficiency of 47 percent. Suppliers may be able to furnish fans having a higher efficiency, thus requiring less horsepower to supply the needed air at specified static pressures.
3. Therefore, in the above example the aeration system for wheat and shelled corn would require a fan that would deliver 1,440 cfm at 7.5 inches of water and a motor that would deliver 10.9 horsepower (possibly a 10 horsepower motor would be satisfactory). Actually, when aerating wheat, only about $3\frac{1}{2}$ horsepower would be required to deliver 1,440 cfm at a static pressure of 7.5 inches of water. However, a motor of this size, would be overloaded when aerating shelled corn in the same bin unless the fan was of the "non-overloading" type.

ELECTRIC MOTORS

Electric motors, available in many different types and sizes, are generally used to drive aeration fans. Most fans require only low to medium starting torque. Most installations are designed for constant speed operation.

The type of motor selected will be dependent upon the electric service available, the power supplier's regulations, and insurance ratings. Existing local codes and ordinances must be complied with in installing motors. A totally enclosed, fan-cooled motor usually is required for aeration duty where grain dust is present and where complete weather protection is needed. The proper motor size for a particular fan installation can be determined from data in the fan manufacturer's catalog. In selecting the size of motor for operating a fan, it is advisable to select at least the size next larger than the fan requirements. Motors may be connected either directly to the fan shaft or by V-belt drives.

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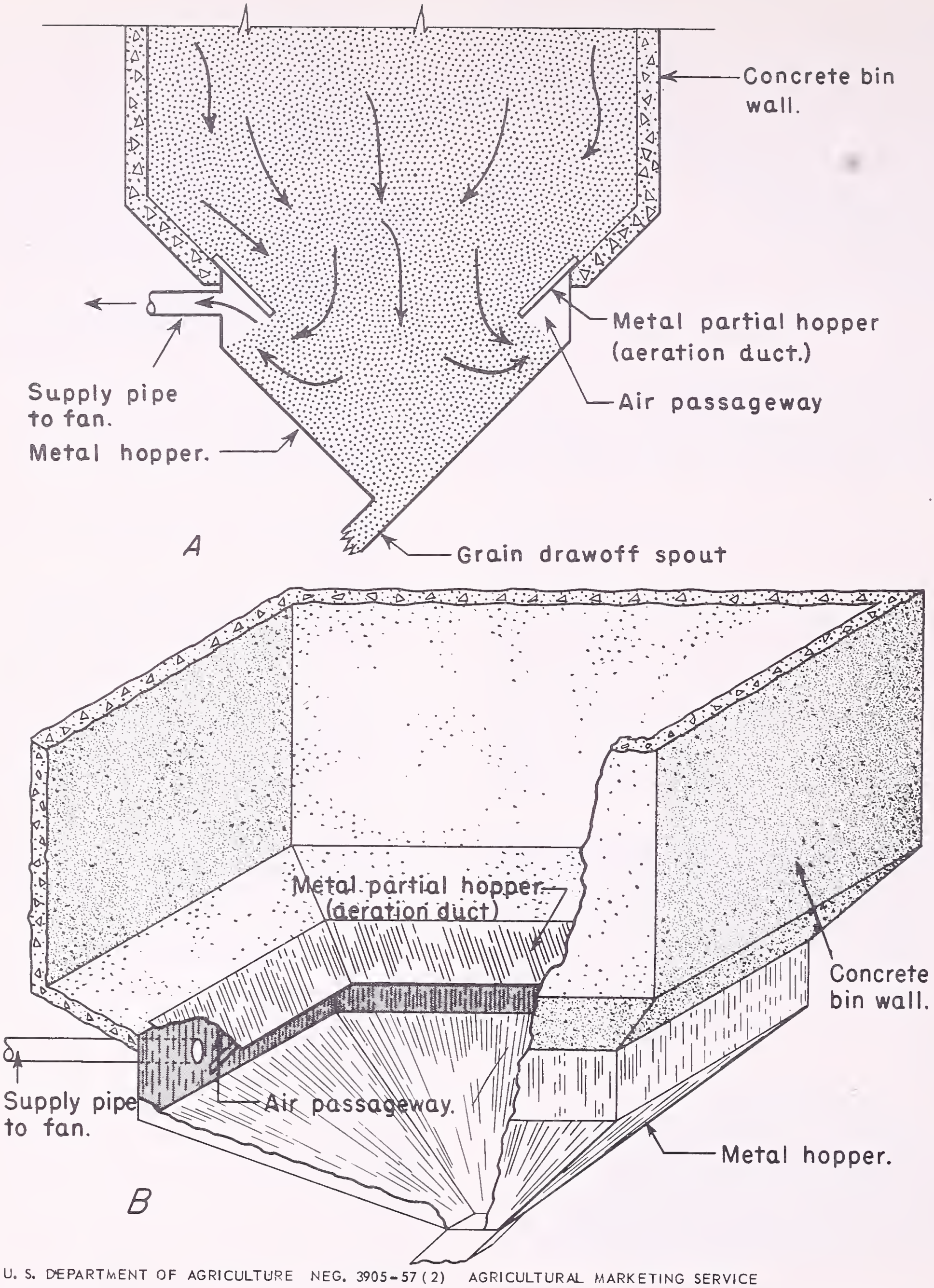

FIGURE 12.—Metal partial hopper installed in a rectangular upright storage to serve as an aeration duct. The hopper also can be installed in circular storages. (*A*) Section through lower part of storage showing grain in place around partial hopper and air passageway. (*B*) Cut-away view of lower part of storage showing arrangement of partial hopper. The performance of the partial hopper can be improved by perforating the hopper to provide additional duct surface area for the air to enter or leave the grain.

Where *three-phase* current is available a squirrel cage induction motor is recommended. These motors are available in all sizes likely to be needed for aeration work, from ⅛ horsepower and upwards. Standard voltages are 110, 220, and 440. Full voltage starting is the rule for these motors up to 30 horsepower. However, some power companies may require low voltage starting on motors in this range.

Single-phase induction motors are suitable for fan operation, but are more expensive than 3-phase motors. Many power companies object to use of single-phase motors over 7½ horsepower.

MOTOR CONTROLS

Control equipment for aeration fan motors should be installed in accordance with the National Electric Code and the requirements of local authorities. The control equipment should include: (1) Means of starting and stopping the motor; (2) means of disconnecting the motor from the power supply; (3) overload and low voltage protection for the motor; and (4) short-circuit protection for the motor and motor-branch circuit.

A motor starting switch, either magnetic or manual, with built-in overload protection is recommended for motors of one horsepower, and larger. Smaller motors should have either overload protection built into the motor or time-delay fuses or circuit breakers rated according to the motor amperage. Fuses or automatic circuit breakers should be included in motor circuits to protect against short circuits in the wiring.

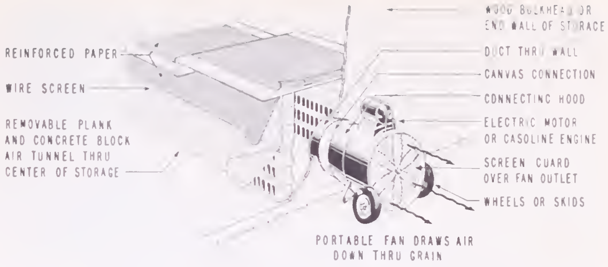

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FIGURE 13.—Aeration fan connected to flat storage equipped with homemade aeration duct. With a canvas connection it is easy to change fan assembly to draw air downward through the grain or to force it upward.

Automatic motor controls are recommended when large quantities of grain are being aerated for a period longer than a few days. A magnetic type starter usually is required where fan motors are controlled automatically by thermostats and/or humidistats. However, smaller motors are sometimes started or stopped directly by the thermostat or humidistat. The contact points of thermostats and humidistats are made for 115 or 230 volts and a small quantity of electric current. For voltages above 230 volts and for amperes above the rated amperage a relay should be used (fig. 23). Where a magnetic switch is used, there must be a manual disconnect switch between the magnetic switch and power supply.

Manual control of fan motors permits the use of more simple switching circuits, but considerable attention on the part of the operator is required to assure satisfactory aeration of stored grain.

OPERATION OF AERATION SYSTEMS

Maintaining the market quality of stored grain by aeration involves the movement of atmospheric air of acceptable temperature and relative humidity through the grain. The quality and moisture content of the grain to be aerated are important. Obviously, aeration can not be expected to substantially improve grain of low market quality.

General operating conditions, and operating information and schedules for various types of storages, kinds of grain, and different geographical areas are discussed in this section.

GENERAL OPERATING CONDITIONS

GRAIN MOISTURE CONTENT

Grain can absorb moisture from or give up moisture to the air surrounding it. Sometimes the grain neither loses nor gains moisture. It is then considered to be at its "equilibrium moisture content" for the temperature and relative humidity of the air surrounding the grain. Some information on equilibrium moisture contents is available for most grains (table 3).

Research results and the experience of commercial operators showing the maximum moisture content and the accompanying relative humidity for the safe storage of grains are presented in table 3.

ATMOSPHERIC CONDITIONS

The temperature and the relative humidity of outside air change frequently with variations occurring each day. However, by proper setting of temperature and humidity controllers, or by determining atmospheric conditions before and during aeration, proper aeration conditions can be assured.

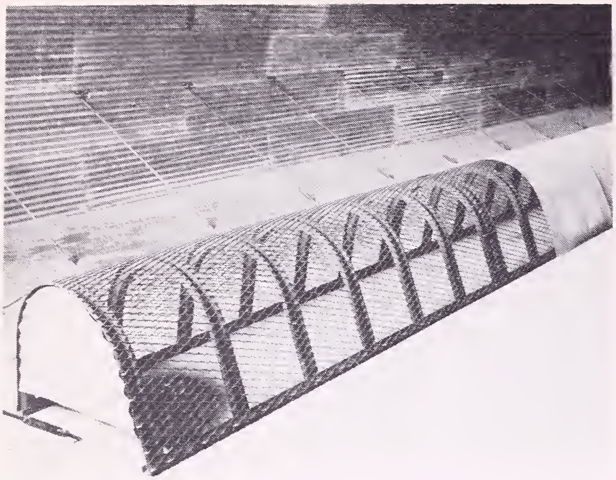

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FIGURE 14.—Flat storage equipped with commercial aeration duct. A single duct, of the proper size, is suitable for storage up to 40 feet wide and 100 feet long.

Air temperatures.—Table 4 lists for several areas the suggested maximum monthly operating air temperatures for cooling grain. These temperatures were selected on the basis of past weather records and results of grain aeration tests. They are suitable for either manual or automatic fan control. Good results have been obtained when fans were operated while the air was at, or below, these temperatures but fans were not operated when temperatures were higher than those listed. Grain was cooled to temperatures equal to or slightly lower than these maximum operating air temperatures and then the fans were stopped.

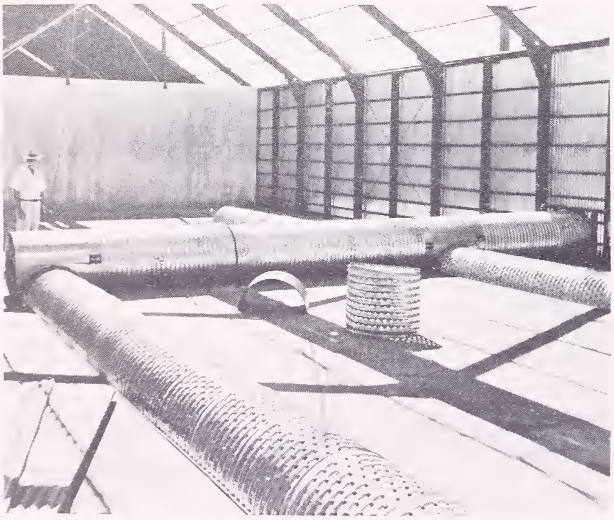

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FIGURE 15.—Semi-circular perforated aeration ducts being installed in a large new flat storage. Because of the size of the storage the fan will be placed on the side of the building to supply air to the two lines of aeration ducts.

Air relative humidity.—It is usually advisable to aerate grain with air having average humidities approximating those listed in table 3. Continuous aeration of storable grain using air with higher humidities will increase the grain moisture. However, aeration with air having a relative humidity as high as 80 percent has been satisfactory where the air temperature is *at least 10 degrees lower* than the temperature of the grain. Grain aerated under these conditions should be checked frequently to make sure no deterioration is taking place. Daily air humidities normally fluctuate over a wide range, from near 100 percent

TABLE 3.—*Maximum moisture content for safe storage and corresponding relative humidities for specified kinds of grains and seeds*

Kinds of grains and seeds	Maximum moisture content for safe storage (wet basis)	Relative humidity of air at which grain is in equilibrium with air (77° F.)
	Percent	*Percent*
Shelled corn, oats	[1] 13. 0	61
Wheat (hard red winter)	[1] 13. 0–13. 5	64–68
Wheat (soft red winter)	[1] 13. 0–13. 5	67–73
Wheat (hard red spring)	[2] 14. 0–14. 5	73–74
Soybeans	11. 0	68
Rice	13. 0	71
Pea beans	16. 0–18. 0	76–84
Grain sorghum	[1] 13. 0	65

[1] Southern areas 12 percent.
[2] Higher moisture limits applicable because of lower average air temperatures in producing area.

TABLE 4.—*Suggested maximum monthly operating air temperatures for cooling grain in specified areas*

Month	Central Plains [1]	North Central [1]	South East [2]	South West [1]
	Degrees F.	*Degrees F.*	*Degrees F.*	*Degrees F.*
July	85	75	85	90
August	85	75	85	90
September	70	65	85	80
October	60	55	70	70
November	50	45	60	60
December	45	45	45	60
January	45	45	45	50
February	45	45	50	50
March	50	45	55	50
April	60	55	60	60
May	70	65	75	70
June	85	75	80	85

[1] Allows 12 or more hours of operation each day under normal conditions.
[2] Allows approximately 6 hours of operation each day at relative humidities below 80 percent.

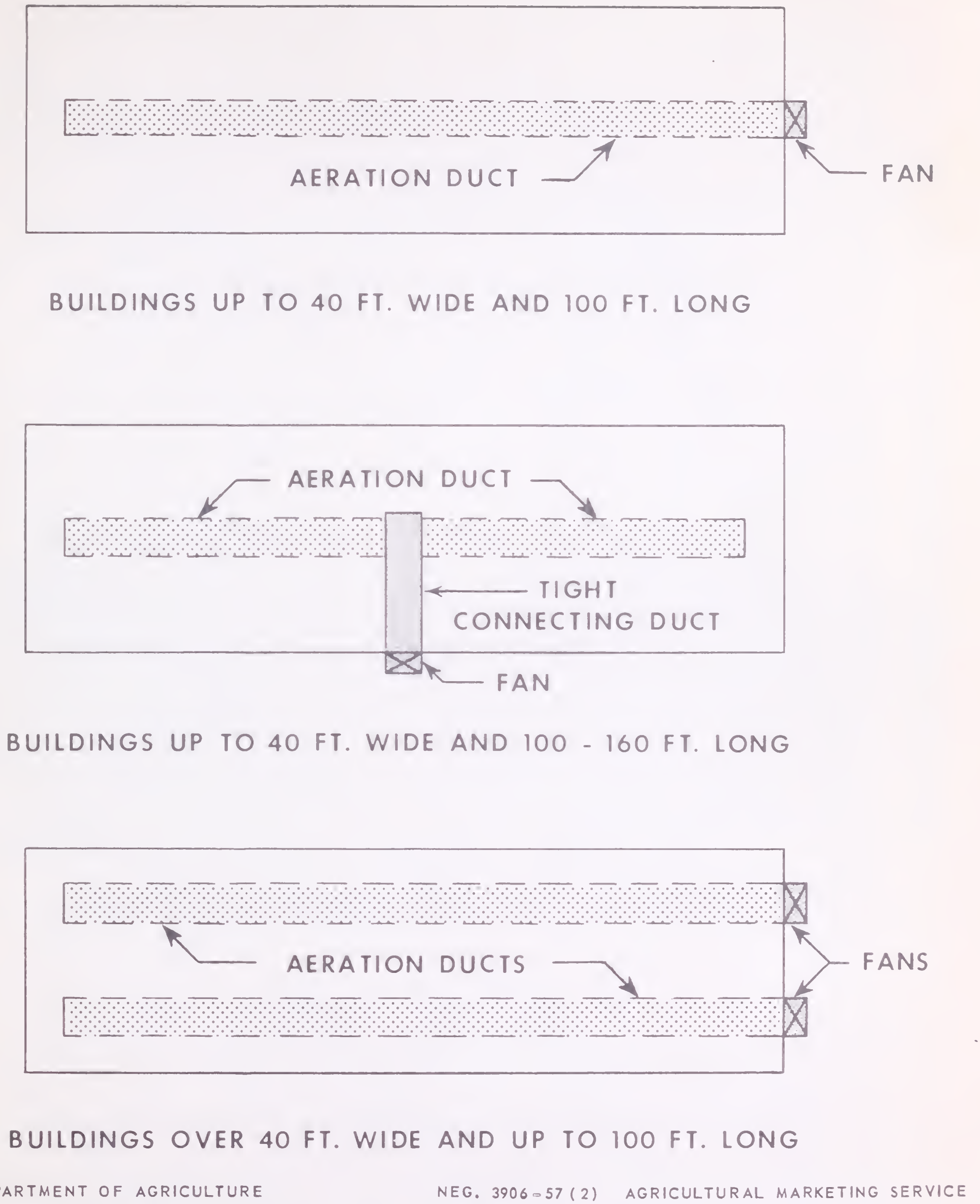

FIGURE 16.—Typical layouts of duct systems for flat storages. Multiples of the above systems may be used for longer or wider buildings.

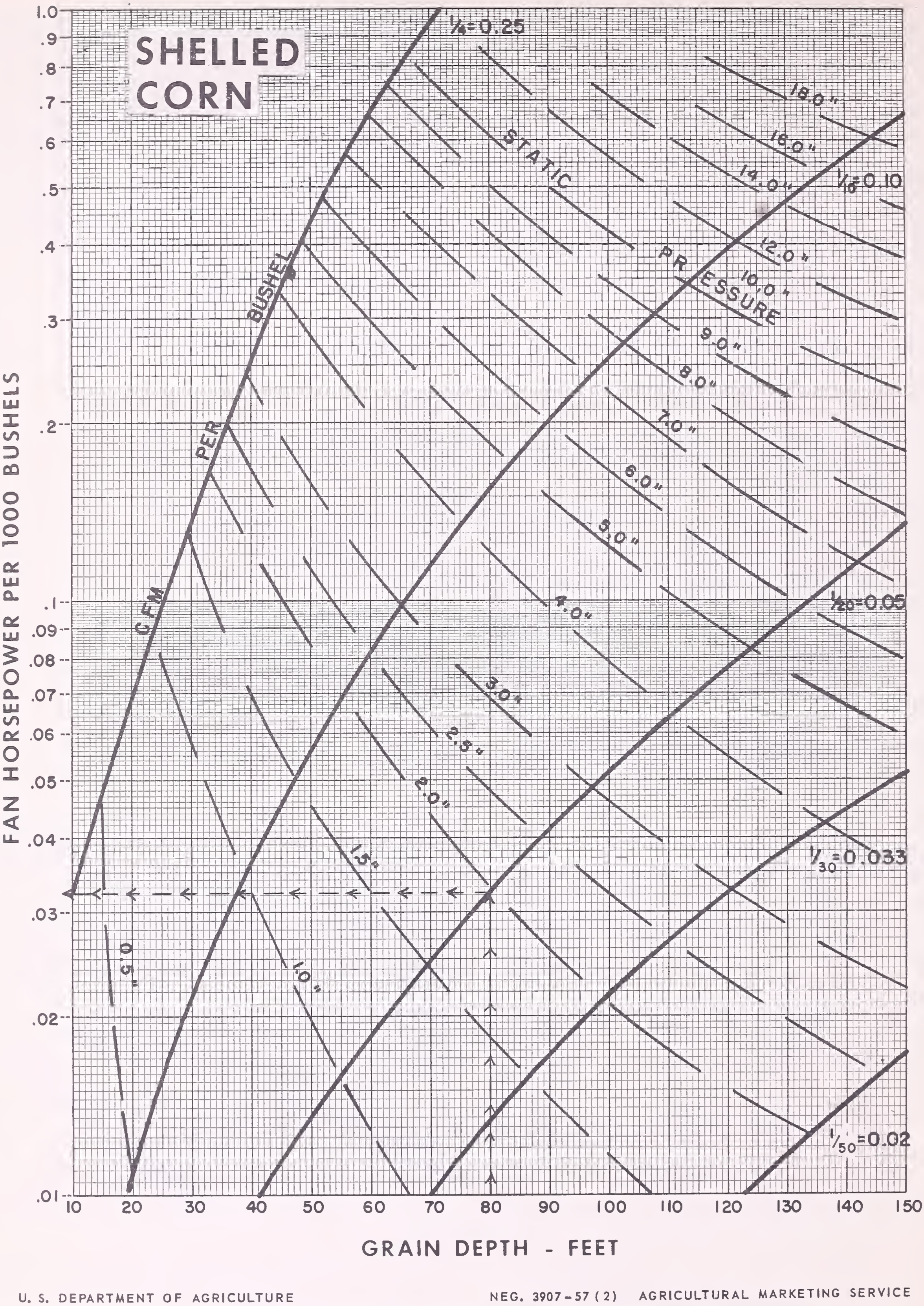

FIGURE 17.—Fan horsepower and static pressure (inches of water) requirements for aerating shelled corn at different rates of airflow (cfm per bushel) and at grain depths ranging from 10 to 150 feet.

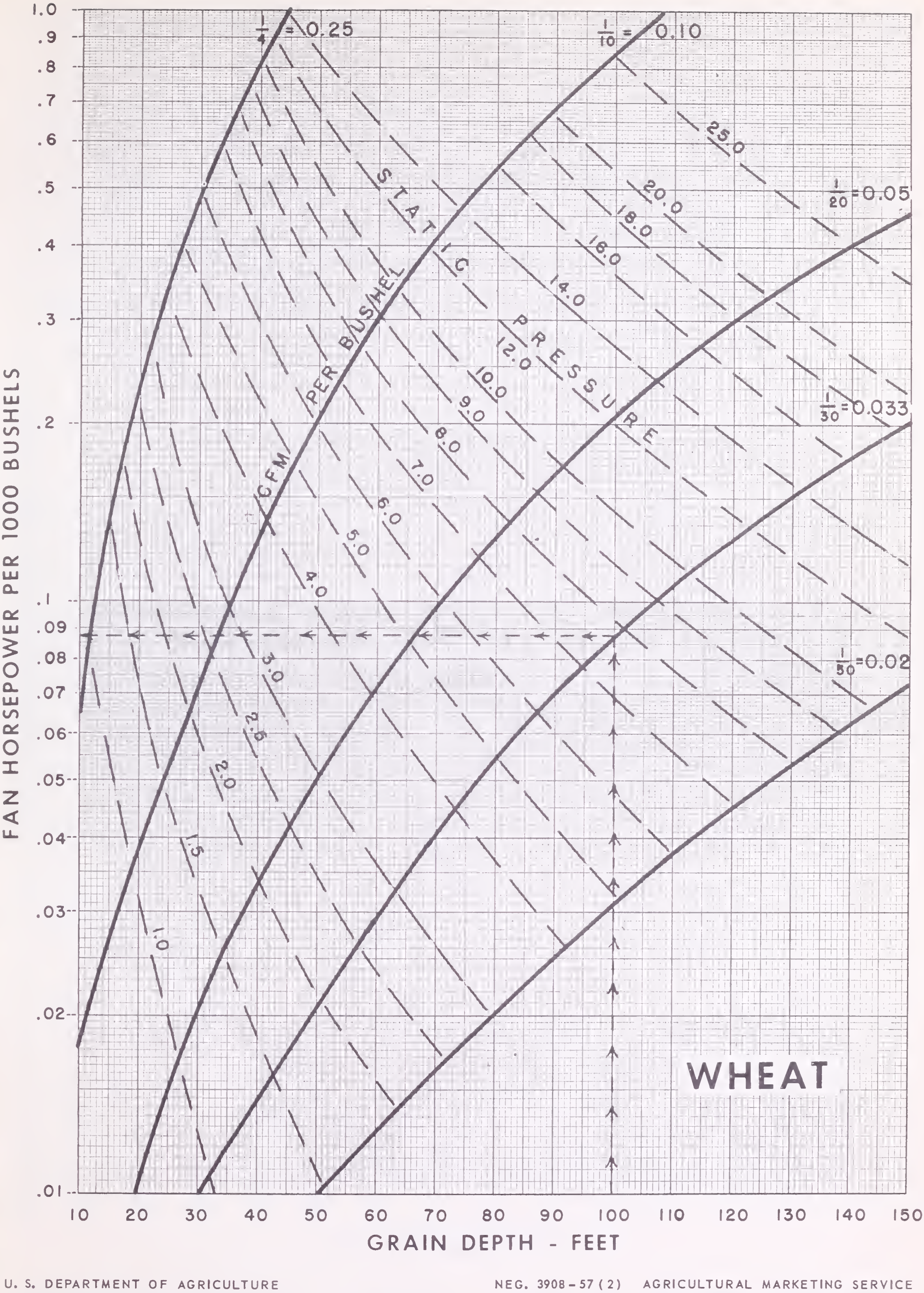

Figure 18.—Fan horsepower and static pressure (inches of water) requirements for aerating wheat at different rates of airflow (cfm per bushel) and at grain depths ranging from 10 to 150 feet.

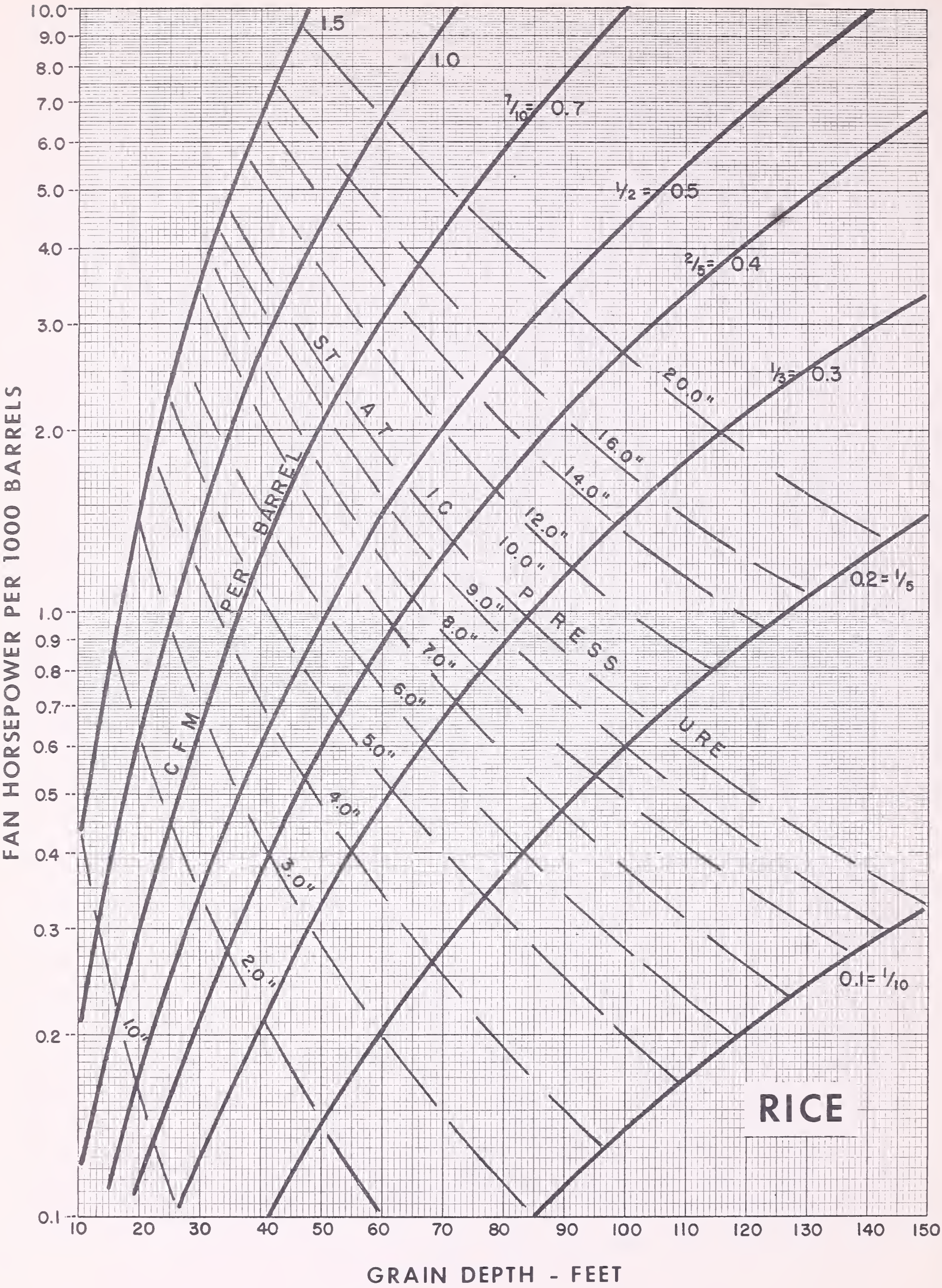

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FIGURE 19.—Fan horsepower and static pressure (inches of water) requirements for aerating rice at different rates of airflow (cfm per barrel) and at grain depths ranging from 10 to 150 feet.

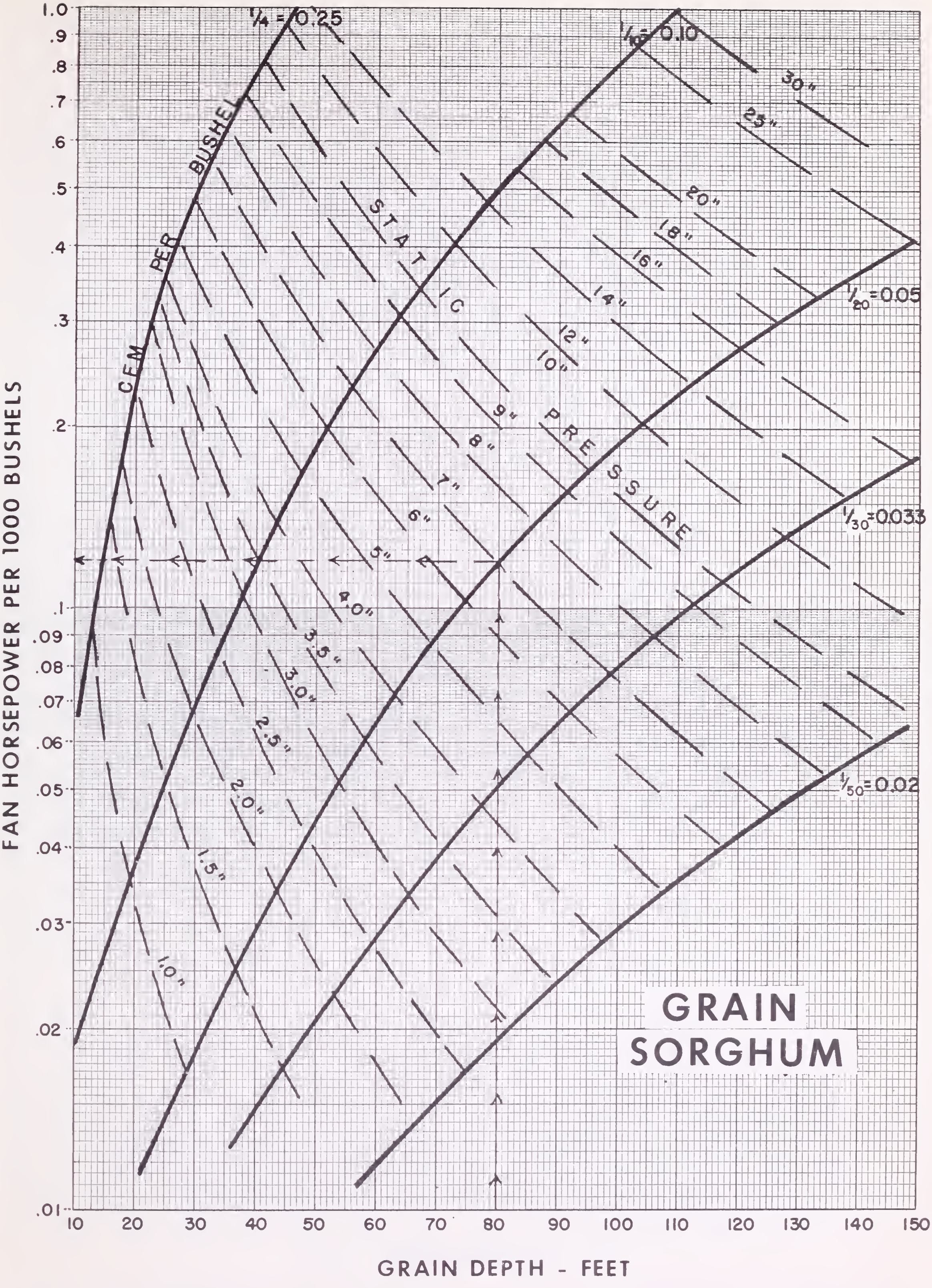

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FIGURE 20.—Fan horsepower and static pressure (inches of water) requirements for aerating grain sorghum at different rates of airflow (cfm per bushel) and at depths ranging from 100 to 150 feet.

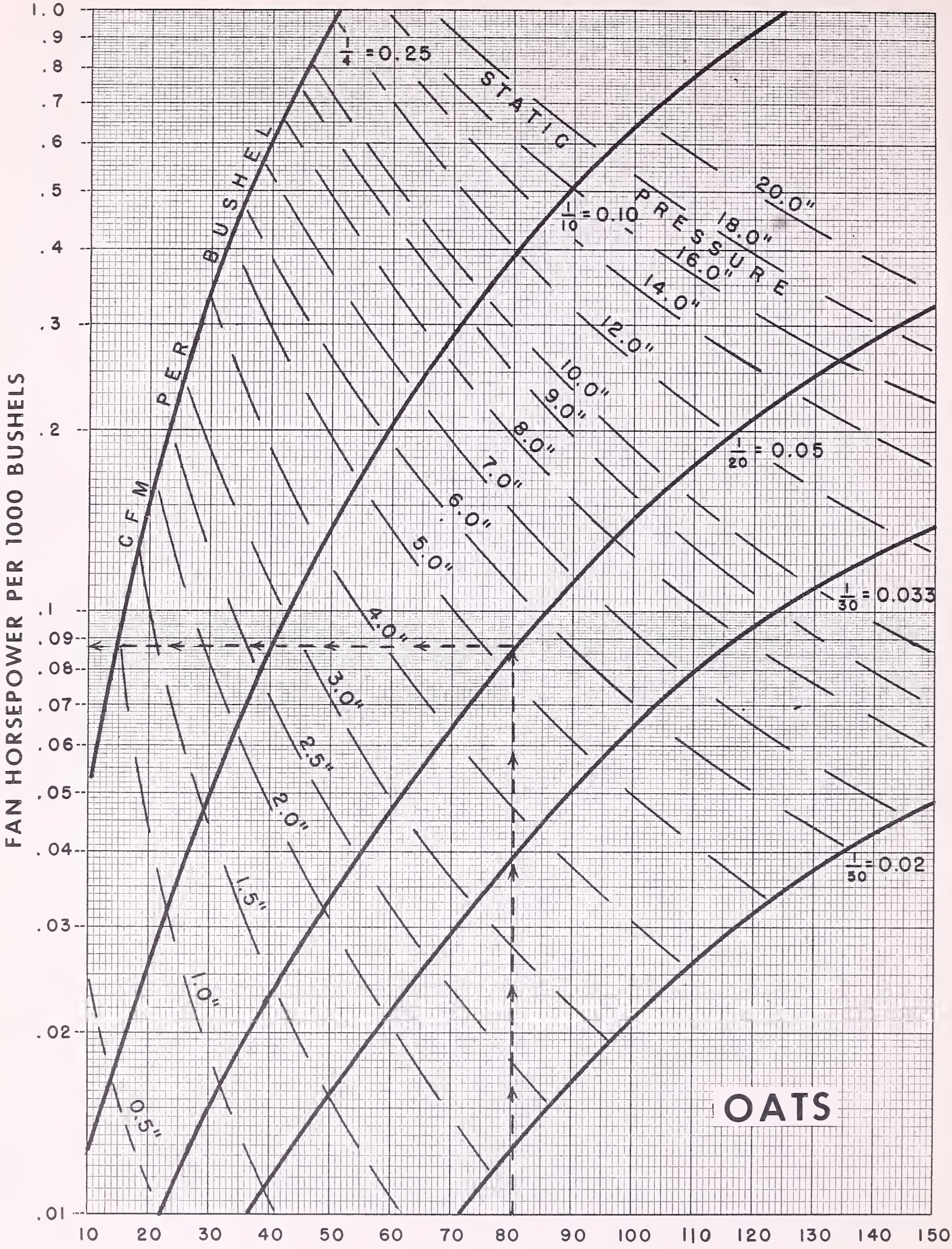

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FIGURE 21.—Fan horsepower and static pressure (inches of water) requirements for aerating oats at different rates of airflow (cfm per bushel) and at grain depths ranging from 10 to 150 feet.

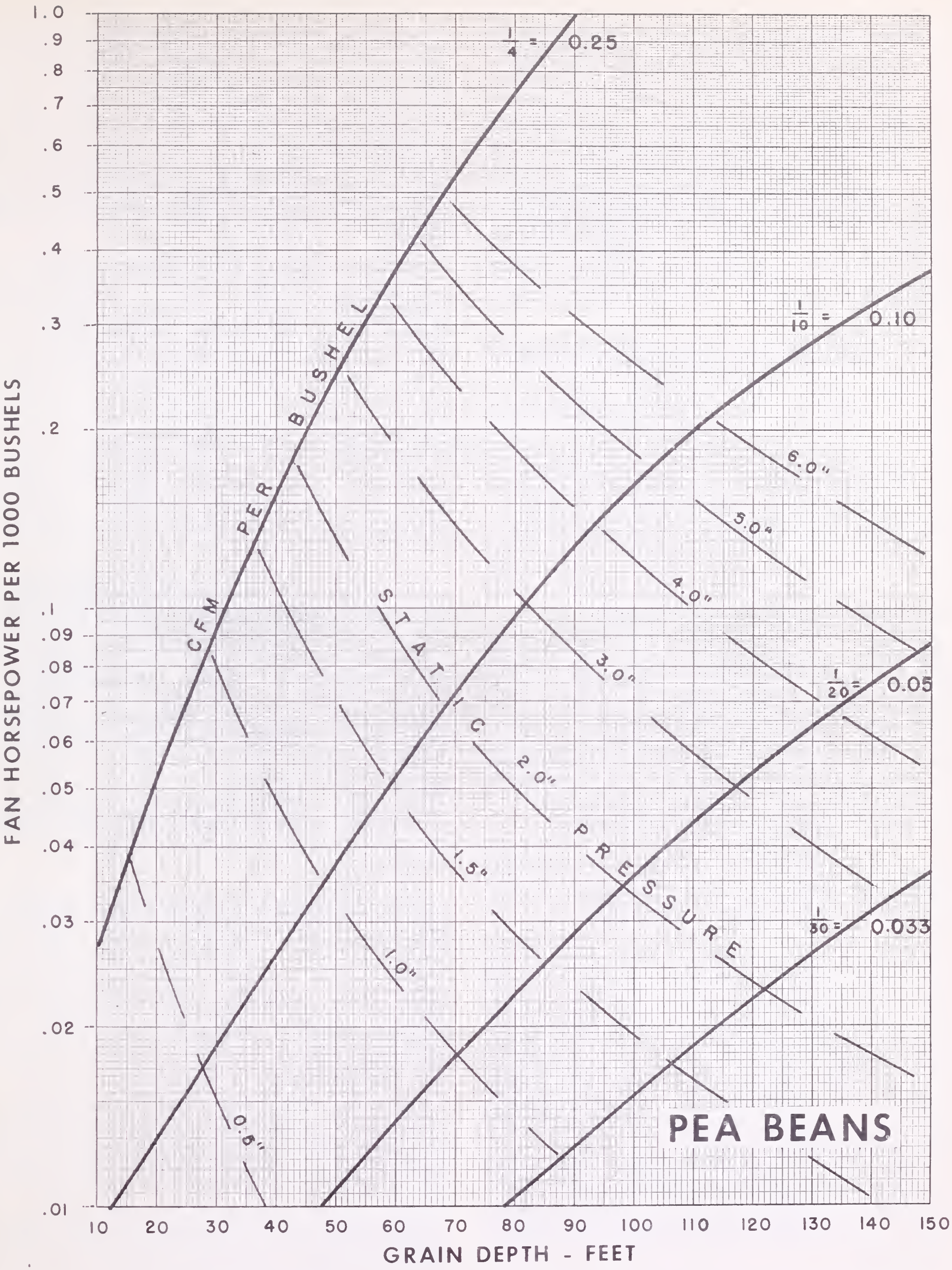

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FIGURE 22.—Fan horsepower and static pressure (inches of water) requirements for aerating pea beans at different rates of airflow (cfm per bushel) and at grain depths ranging from 10 to 150 feet.

at night and early morning down well below 60 to 70 percent on clear days. Therefore, fans need to be stopped only when the average daily humidity exceeds the limits outlined above. However, if grain having temperatures of 95° to 100° F., or higher, and having some excess moisture, goes into storage, it may be desirable to run the fan when air humidities are above 80 percent. Some cooling will be accomplished and aeration airflow rates usually are so low that any moisture change in the grain will be extremely slow. A humidistat may be used to stop the operation of the fan when humidities are high and during periods of rain and fog. This also may be done manually.

GRAIN MOISTURE CHANGE DURING AERATION

Drying.—Some drying generally occurs when grain is cooled by air. In passing through the grain the cooling air is warmed and is able to hold more moisture as its temperature is increased. Any increased moisture in the cooling air must come from the grain. It is estimated that in cooling grain from 50° F. down to 30° F. it is possible to reduce the grain moisture by $\frac{3}{10}$ percent or more; in cooling from 90° F. down to 40° F. by 1 percent or more. This drying also influences the cooling rate and the amount of cooling resulting from evaporation of moisture is considerable.

Wetting.—Grain near the air entrance may be cooled to air temperature long before grain temperatures are reduced in other parts of the storage. Some moisture may be added to this cooled grain before aeration is completed. However, there is little danger of excessive wetting of the grain unless: (1) The grain is cooler than the air being moved through it; and (2) aeration is continued in high humidity weather *after* the grain has cooled to near air temperature.

COOLING DIFFERENT KINDS OF STORED GRAIN TO PREVENT OR MINIMIZE MOLD GROWTH AND INSECT ACTIVITY

Cooling stored grain to prevent mold growth and insect activity includes removal of both natural heat and heat from artificial drying. Aeration for these purposes is used more in the warmer, southern areas than in northern areas. In the South grain often goes into storage at 90° F. or higher and should be cooled as soon as atmospheric conditions permit. Grain going into storage in the northern areas during the summer months also should be cooled.

There is no one optimum storage temperature for grain. The moisture content of the grain, its probable use (for food, feed, oil, seed), and the length of the storage period (weeks, months, or years), are factors that determine the storage temperature.

Most grain molds grow slowly or not at all below 70° F. when grains have moisture contents in line with those shown in table 3.[5] Insect reproduction is stopped, or nearly so, at temperatures below 60° F. Moreover, many insects die from starvation when grain temperatures drop to 40° F. for any length of time. Most species, excluding moths, are killed in 2½ months' time at a temperature of 35° F.[6] (Although aeration is useful in providing lower grain temperatures that help to prevent serious insect infestation and consequent grain loss, it will not entirely replace fumigation and other direct means of insect control.)

General storage practice indicates that a grain temperature of about 50° F. is satisfactory, particularly if there is a chance of the grain being moved during hot weather. Apparently grain at 50° F. can be moved during the summer with little danger of moisture condensation and subsequent spoilage. Grain temperatures of 35° and 40° F. have proven staisfactory where the grain was not moved during warm weather.

Fans should be started as soon as the storage is filled with warm, summer-harvested grain if atmospheric conditions are suitable. Grain temperatures should be lowered as soon as possible to minimize mold growth and insect activity.

As aeration progresses a cooling zone is established which moves through the grain in the direction of airflow (fig. 24). All the grain behind the cooling zone will be near the entering air temperature; all ahead of it will be near the initial grain temperature. While the cooling zone is passing through the entire grain depth, the cooling process will approach 100 percent efficiency. With the low airflow rates used to aerate deep upright storages, the process may be 100 percent efficient for 75 percent, or more, of the time. With higher airflow rates and more uneven air distribution in flat storages, cooling may approach 100 percent efficiency for only 25 percent, or less, of the time.

The higher the grain temperature the more the air will be warmed while it passes through the grain, and each pound of air will carry away additional heat. Therefore, about the same length of time is required to cool all grain to air temperature, regardless of the initial grain temperature (fig. 25). However, when the grain moisture content is reduced during aeration, the additional cooling resulting from the evaporation of water will shorten the cooling time.

As grain cools by zones (fig. 24), the airflow must be adequate to move the cooling zone through all the grain within an allowable time limit. There is danger of grain deterioration in that part of the bin cooled last, particularly in warmer climates.

[5] Carter, Edward P., and Young, George Y. Effect of Moisture Content, Temperature, and Length of Storage on the Development of "Sick" Wheat in Sealed Containers. Cereal Chem. 22:418–428, Sept. 1945. Tables 1 to 5.

[6] U. S. Department of Agriculture. Farmers Bulletin 1880, Control of Insect Pests of Grain in Elevator Storage.

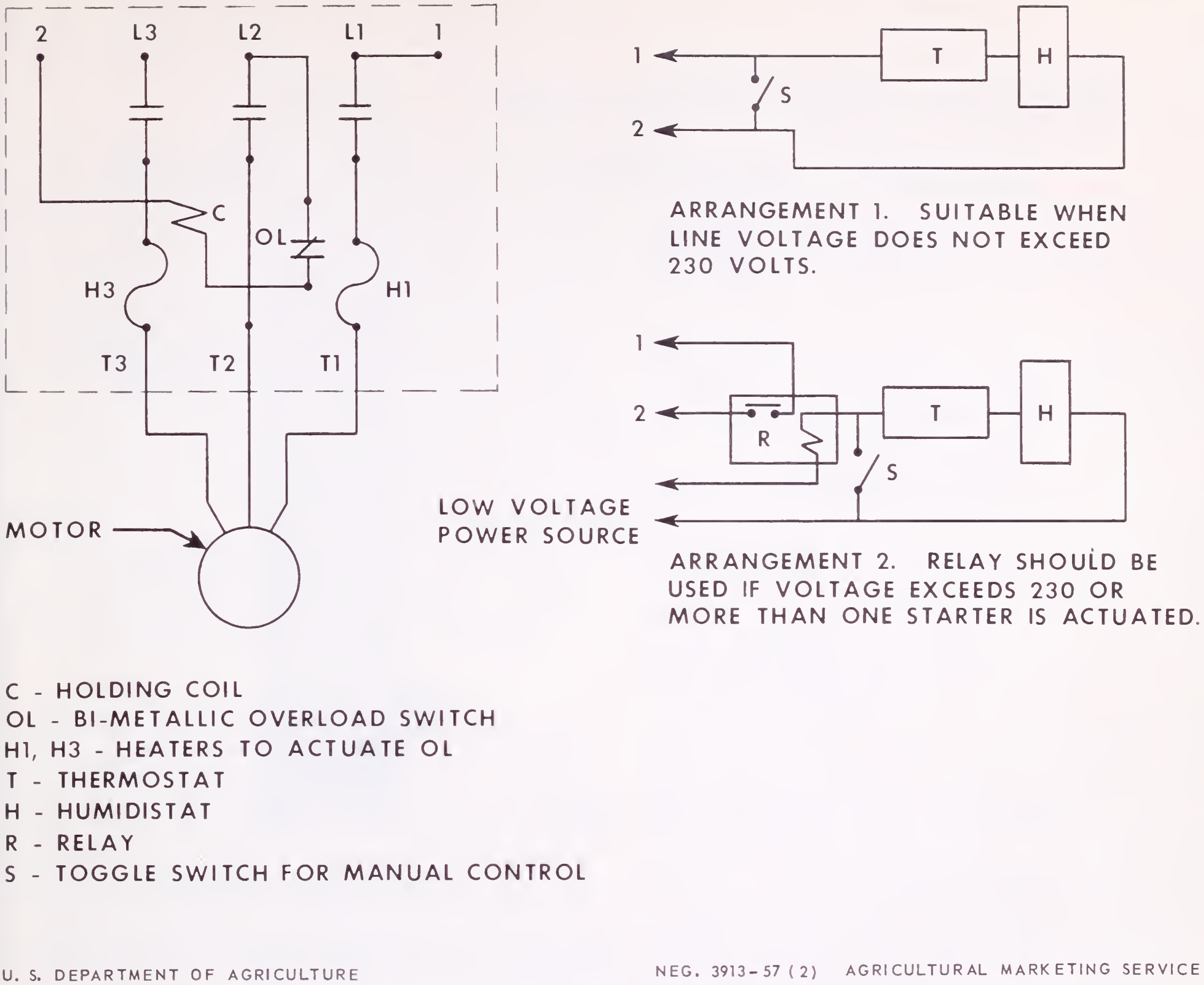

FIGURE 23.—Magnetic starter, circuits, and actuators for automatic control of aeration fans.

This factor is the most important consideration in establishing time limits for completing cooling. Reasonable power requirements and favorable aeration weather also must be considered in selecting airflow rates.

The time required to complete a cooling stage (time for moving a cooling zone entirely through stored grain) will vary with the airflow rate used, the amount of cooling resulting from evaporation of moisture from the grain during aeration and the quantity of broken kernels and foreign material present in the grain. For example, where some evaporative cooling can be expected (initial grain temperature 75° to 100° F.) during aeration from 3 to 4 days will be required with an airflow rate of 1/10 cfm per bushel; and from 15 to 18 days with an airflow rate of 1/50 cfm per bushel. Where little evaporative cooling can be expected (initial grain temperature 75° F. and below) the aeration time may be doubled. The southern areas generally have shorter periods of cooler weather than the northern areas. Therefore, the higher airflow rates are desirable for faster cooling during favorable weather conditions in the South (table 1).

Ordinarily grain in *upright storages* is cooled by aerating the grain by successive stages during the summer, fall, and winter seasons. Each cooling stage begins when substantial cooling becomes possible with each seasonal change. This method provides some grain temperature reduction soon after the grain is stored which helps to hold insect activity and mold development to a minimum.

Some study has been given to cooling grain by a single stage. With this method aeration is postponed until later in the season when the air temperature is low enough to cool the grain to the

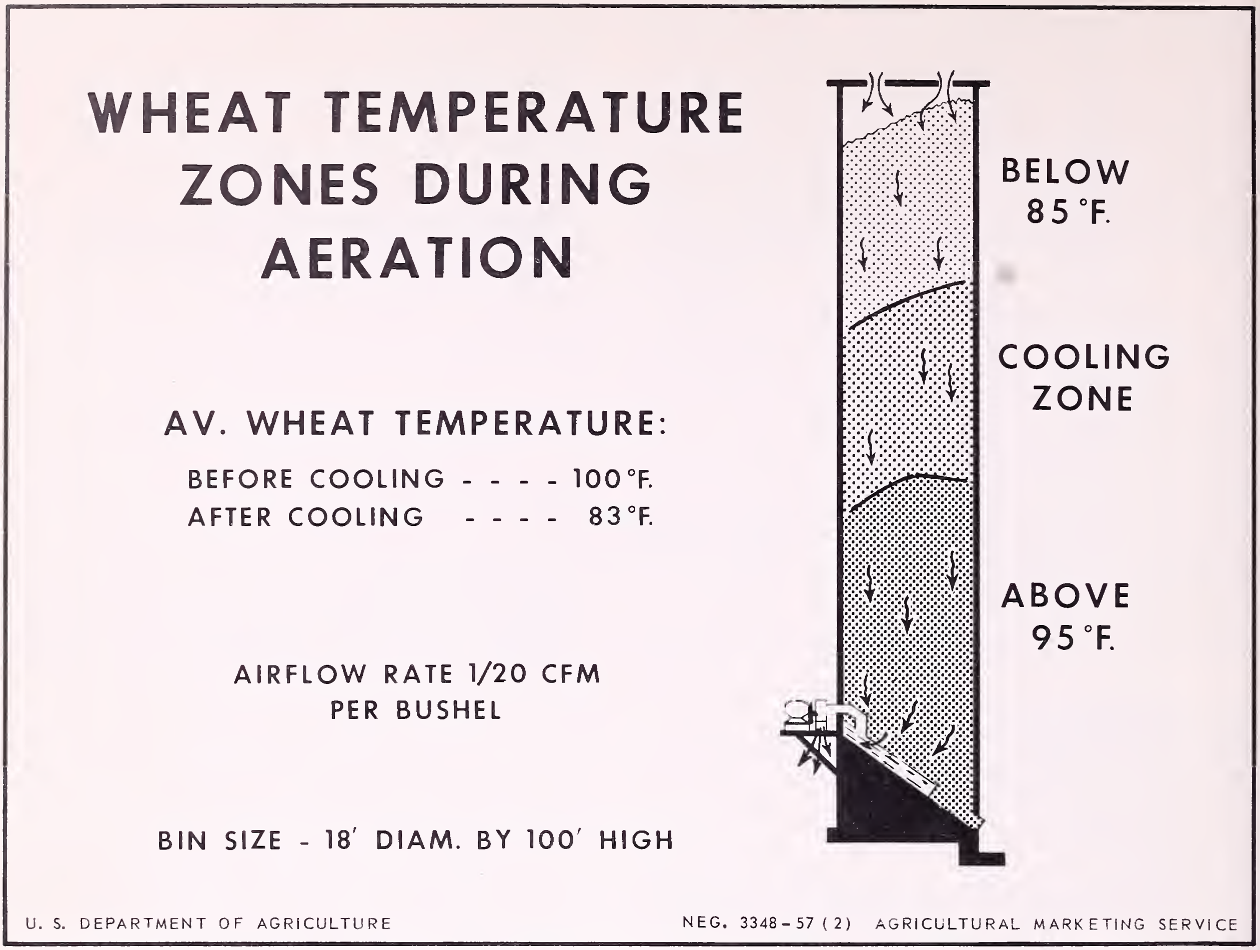

FIGURE 24.—Wheat temperatures in a grain storage during aeration illustrating the cooling zone existing during the cooling period. Temperature patterns in this bin indicate some non-uniformity of airflow. Apparently this is partially due to the uneven grain surface and the hopper bottom.

desired temperature. One objection to this method is that aeration may be started so late that some grain deterioration and/or moisture migration may have already occurred. Operating costs for single stage cooling are less than for cooling by successive stages. Single stage cooling is not suitable for equalizing grain temperatures to prevent moisture migration. (See section on equalizing stored grain temperatures.)

By use of either plan, once a cooling zone has been started through stored grain it should be moved on through. Otherwise there may be areas in the bin (the cooling zone) where the grain temperatures may vary enough to cause some spoilage (fig. 26).

Frequently, grain in *flat storages* can be cooled to near air temperature in 3 to 7 days. Thus, the grain can be cooled in successive stages as outdoor temperatures drop.

Cooling grain in *farm-type storages* can be accomplished by: (1) Continuous operation with a small fan on each bin, (2) portable fans moved from bin to bin, or (3) one fan connected to several bins, operated similar to that discussed for flat storages. If a portable fan is used, the airflow rate should be adequate to cool one bin in a week. The fan may be rotated among the bins several times in order to lower the grain temperature by stages as the outside temperature falls.

For cooling, aeration fans usually are operated to draw air downward through stored grain. There are indications that in the warmer southern areas there may be some advantage in forcing air upward through the grain. The chief advantage of this "reverse flow" appears to be that trapped heat under the roof of the bin can be forced out at the top of the bin rather then pulled down through the grain. Another advantage is that during the summer the ground usually keeps the grain at the bottom of the storage cooler than the grain at the top. With the air forced upward, the warmer grain at the top may be cooled without

moving warm air through the cooler grain at the bottom. This may shorten the cooling time and thereby reduce the cost.

GRAIN SORGHUM

Continuous operation is recommended as soon as the storage is loaded with warm dried grain to remove residual heat left in the grain by the drier. As soon as the initial cooling zone has moved through the grain, the cooling schedule should be changed to intermittent operation. When outside air temperatures are high, fans may be operated only 4 or 5 hours per week; just enough to prevent or remove storage odors. As soon as outside air temperatures begin to fall, cooling by successive stages should be started. Grain temperatures should be reduced by stages of about 10 to 15 degrees. Controls which will operate the fan only during prescribed weather conditions are recommended. As good cooling weather exists for extremely short periods in Southwest grain sorghum areas, much suitable operating time may be lost if controls are not used. Operation at night is desirable in these areas as cooler temperatures are available.

RICE

Common practice in drying rice is to alternate drying "passes" and tempering periods when rice is stored to equalize kernal moisture. Aeration helps to hold the partially dried rice in good condition and to speed up the tempering process, and is also helpful during the holding period before moist rice goes to the drier. Continuous fan operation is recommended for both purposes.

As rice usually is harvested in the fall, some cooling can be done immediately after drying, by operating the fan at night when the air temperature may be 10 to 15 degrees below rice temperatures. Whenever cooling is started it should continue—at the same temperature setting—until the cooling zone is moved entirely through the bin. The zone may be moved through in several days, or it may require as long as a month, depending upon weather conditions. Cooling by stages should continue as the weather progressively becomes cooler until an average rice temperature of around 40 to 50 degrees is attained.

WHEAT AND OTHER SMALL GRAINS

In the Central Plains area, aeration by successive stages has been used to cool wheat from 100° F. down to 85° F. in the summer immediately after harvest; from 85° F. down to 60° F. in the fall; and from 60° F. down to 40° F. in early winter (fig. 27). In the Southeast and some northern areas similar operations have been used to cool wheat and other small grains that were harvested and moved into storage during the summer. Grain temperatures often can be reduced to 70° F. or below during July and August in the northern areas.

SHELLED CORN

Although shelled corn moves into storage later in the fall in the southern areas there is considerable advantage in reducing corn temperatures by aeration. Operations for cooling corn in these areas are much the same as those for cooling wheat.

Although in the northern areas corn may be aerated to reduce high grain temperatures, the main purpose of aeration is to equalize grain temperatures to prevent moisture migration (see next section).

EQUALIZING STORED GRAIN TEMPERATURES TO PREVENT MOISTURE MOVEMENT FROM WARM TO COOLER GRAIN

Temperatures of stored grain are equalized to prevent moisture from moving from warm to cooler grain. This moisture movement is normal in any storage where appreciable variations in grain temperatures exist, but it is most pronounced in the colder, northern areas. During the fall and winter months grain located near exposed walls and upper surfaces cools more rapidly than that in the center of the bin. This temperature difference causes slow convection currents in the bin with the warm air, which rises through the center of the grain mass, carrying moisture from the warmer grain to the colder surface grain. Moisture accumulation may be serious enough to cause molding and crusting on the grain surface and spoilage in other parts of the bin. In stored grain having uniform temperatures, moisture migration does not take place.

Aeration to equalize stored grain temperatures is started when the weather becomes cooler during early fall. The fan can be started when the air temperature is 10 to 15° F. below that of the warmest portion of the stored grain.

To equalize stored grain temperatures, fans usually are operated to draw the air downward through the grains for two reasons: (1) The natural tendency of the convection currents to move upward from the warm grain toward the cool upper surface is in part offset; and (2) the exhaust air which is usually comparatively warm and moist, is expelled through warm grain in the lower part of the bin and not through the colder upper grain surface where some condensation might occur. Airflow rates shown in table 1 are suitable for equalizing grain temperatures.

In both *flat* and *upright* storages fan operation usually is intermittent. By use of the higher airflow rates practical in flat storages the fan is operated about one week each month, from September through December or January. Or, it is operated until grain temperatures are fairly uniform throughout the storage.

In large upright storages fans usually are operated daily during the fall and winter months when air conditions are suitable. Automatic

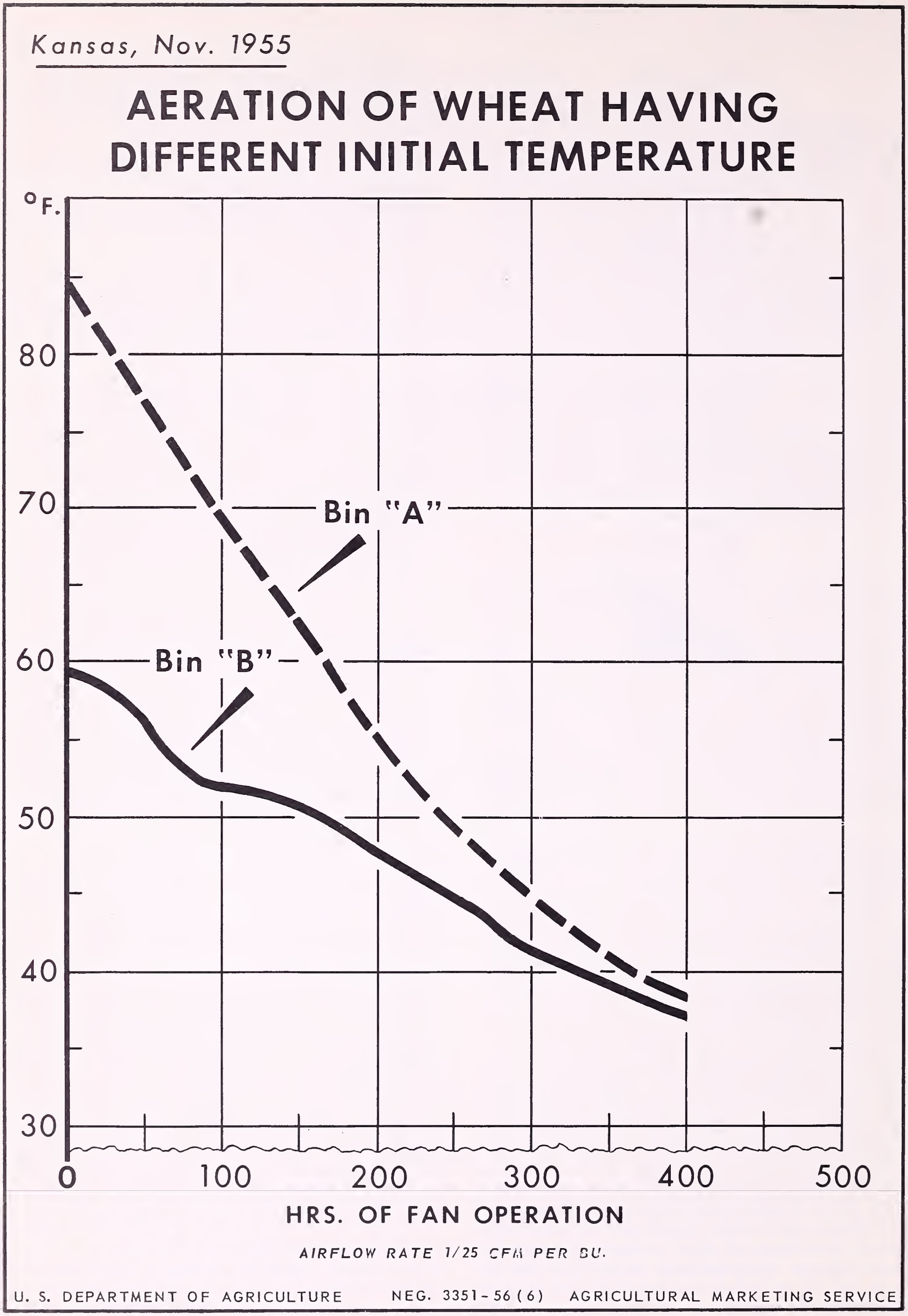

Figure 25.—Grain cools to near air temperature in about the same number of hours of fan operation regardless of initial grain temperature. The average air temperature ranged between 25° to 43° F. during the cooling period.

control is recommended so as to take full advantage of favorable weather. One thermostat can be set to turn the fan off when the air temperature is about 5° above the desired final grain temperature. A second thermostat in the control circuit can be set to stop the fan when the air temperature falls from 5° to 10° below the desired temperature. Although control of the fan within these narrow temperature limits tends to give more uniform grain temperatures, it may limit fan operation and thus extend the aeration period.

Continuous aeration during fall and winter with airflow rates of 1/30 cfm per bushel, and less, has been satisfactory in the smaller, *farm-type bins*. This method requires the least amounts of labor and control equipment. However, occasional checking is necessary to make sure no excessive moisture increases occur anywhere in the stored grain. In smaller storages much of the grain near the walls, ground, and top surface is exposed to outside temperatures, in which case only enough air is needed to cool the grain in the center of the bin. The aeration duct may be arranged to pass most of the cooling air through this part of the grain.

The foregoing operating suggestions apply to shelled corn, wheat, and other small grains; and to soybeans stored through the fall and winter in the northern areas. They also apply to other areas where grain temperature differences are great enough to cause moisture migration and accumulation.

Continuous fan operation is not recommended for pea beans because of highly variable weather conditions in producing areas. Operation during the fall and winter months should be limited to periods when the air temperature ranges between 30 and 45° F. For aeration during the spring months, a higher temperature range may be necessary to insure adequate fan operation. Pea beans are not normally stored through the summer months.

Pea beans, and, to some extent grain, are subject to serious breakage if handled when excessively dry. Indications are that moisture can be added to "toughen" the seed coat and thus reduce damage. However, there is little information now available to substantiate this point. Wetting is slow unless the grain is more fully exposed to humid air than under normal aeration procedures. Since wetting proceeds by layers similar to cooling, grain first exposed to humid air may develop mustiness before moisture can be added to the entire lot.

MOISTURE CONDENSATION IN SURFACE GRAIN

It has been repeatedly demonstrated that aeration during the fall and winter is *beneficial*; it will prevent excessive migration of moisture from the warm area in a bin to the top layer of grain. A similar, but less obvious, migration and accumulation of moisture frequently develops in the cold subsurface layers of grain during the spring season. Aeration during the spring prevents this moisture accumulation. Tests are now underway to determine: (1) Optimum grain temperatures that prevent this subsurface accumulation of moisture during the spring and summer, and (2) the minimum periods of fan operation necessary to prevent such accumulations of moisture.

MOVING COLD GRAIN DURING WARM WEATHER

In the northern grain producing areas it is possible to cool grain below freezing temperatures. These low temperatures will kill stored grain insects, and also may stop or retard various deterioration processes. However, warehousemen have found that low storage temperatures also may have disadvantages. The risk of moisture accumulation beneath the grain surface is increased. Moreover, if cold grain must be moved or shipped during warm weather some condensation of moisture on the grain may occur and there is danger of some grain spoilage. Grain at 45° to 50° F. can be moved during hot weather with little danger of spoilage.

REMOVING ODORS FROM STORED GRAIN

The "fresh" grain smell is one of the most striking characteristics of aerated grain. Molding and rancidity of grain causes common storage odors. This condition is minimized by cooler storage conditions and aeration will either remove or reduce such odors. Some odors can be rapidly dissipated with only a few air changes, while others are more persistent and require longer periods of aeration. Some odors are removed only temporarily or reduced in intensity by aeration. Sour or fermented odors are seldom removed entirely by either aeration or drying.

Although little factual information is available in regard to the operational requirement for removing odors, fans usually are operated from 30 minutes to 1 hour, or longer, once every 2 to 4 weeks, or whenever the operator thinks it desirable. With airflow rates recommended for aeration, from 5 to 20 minutes are required for one complete change of air in the stored grain.

APPLYING FUMIGANTS TO STORED GRAIN[7]

The introduction of fumigants through an aeration system is a practical method of fumigating grain (fig. 28). The distribution of fumigants

[7] Phillips, G. L., Grain Fumigation, Agr. Chem. X(1): 55–56, 117–121; X(2): 41–43, 133–135, Jan., Feb., 1955. Phillips, G. L., Experiments on Distributing Methyl Bromide in Bulk Grains with Aeration Systems, AMS–150, 1957. Phillips, G. L., Experiments on Distributing Liquid Grain Fumigants in Bulk Grains with Aeration Systems, AMS–151, 1957. Phillips, G. L., Experiments on Distributing HCN in Bulk Grain with Aeration Systems, AMS–152, 1957.

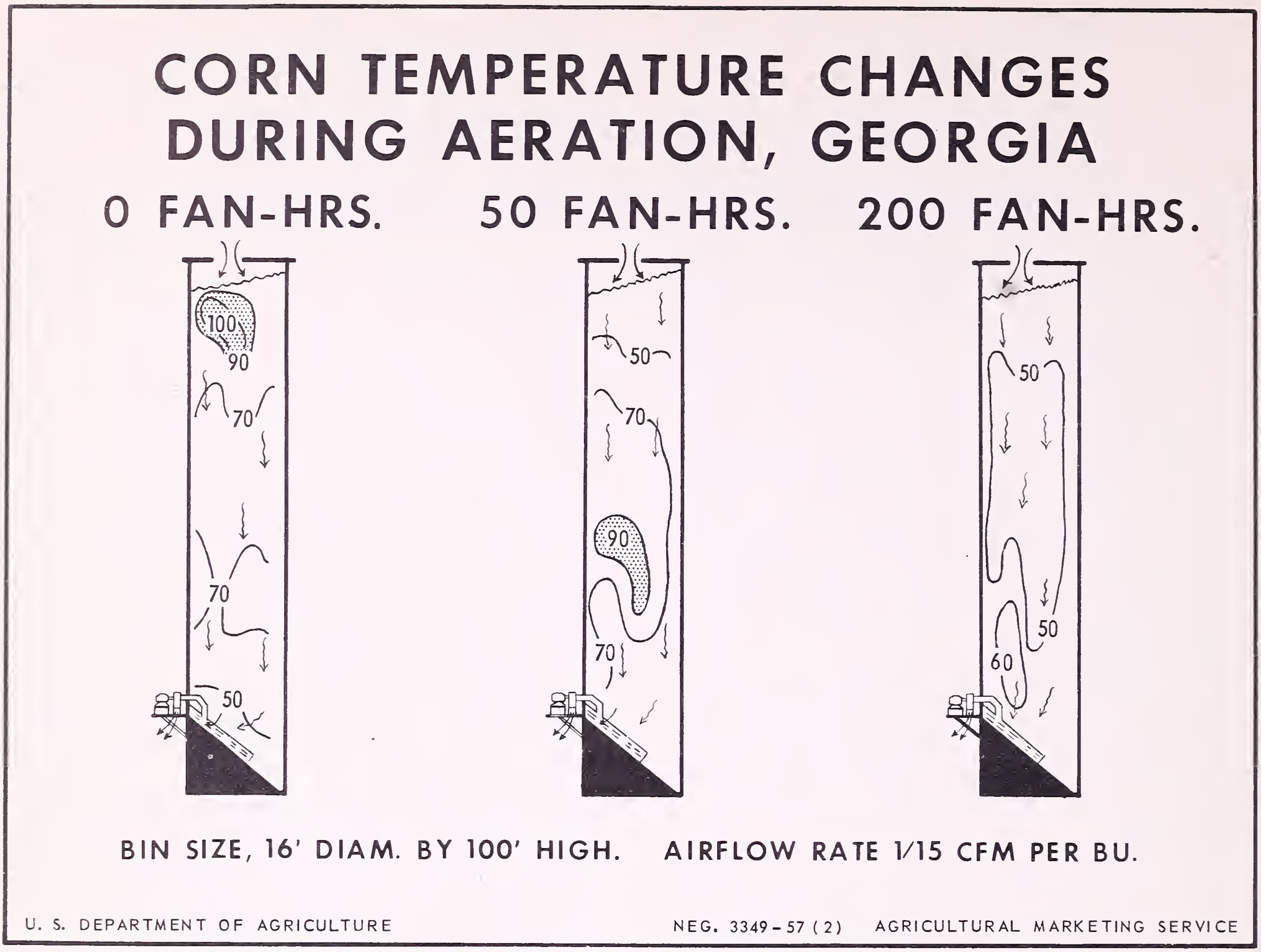

FIGURE 26.—Corn temperature patterns in this Georgia storage illustrate how "hot spots" may not cool down but move on out of the grain during aeration.

is usually more uniform and the dosage required is less than for other methods. The fumigants may be purged from the grain after a prescribed exposure period by operating the fan for a few hours.

With uniform airflow the fumigant can be introduced into the grain in the time required for one air change. It is desirable to allow from 10 to 20 minutes to meter the fumigant into the airstream, which requires an airflow rate of from $\frac{1}{20}$ to $\frac{1}{40}$ cfm per bushel.

Higher airflow rates can be used for fumigation in a closed system. In this system the fumigant is recirculated through the grain. Optimum grain temperatures for effective and economical application of fumigants differ according to the method of application. When applied to the surface of stored grain the grain temperatures should be at least 65° F. This is necessary for penetration of fumigant to the bottom of the grain bulk in killing concentrations.

Grain temperatures are less important when aeration equipment can be used for applying fumigants. Effective distribution of the fumigant to all portions of the grain bulk is possible under a fairly wide range of grain temperatures.

HOLDING MOIST GRAIN IN STORAGE FOR BRIEF PERIODS

Aeration reduces the hazard of spontaneous heating when it is necessary to hold moist grain in storage for brief periods. Continuous aeration removes heat generated by mold growth, the principal source of heat, and also helps to slow down mold growth and other deterioration by reducing grain temperature. However, definite upper limits of moisture and temperature have not been established for moist grain under aeration.

Aeration may be used during periods of heavy receipts of moist grain. By providing safe holding conditions, the load on the drier can be spread out and more grain handled during a given harvest period.

USE OF GRAIN TEMPERATURE INDICATORS

Most grain storage operators closely follow temperature changes of the grain they have in storage. These changes, together with other quality indexes, influence their schedules for aeration or for turning grain from unaerated bins. Where the grain is aerated, and little or no turning is done, it is especially important that dependable temperature indicating equipment be installed and used.

The most common grain temperature indicators are mercury thermometers and thermocouples. Bimetallic and recording thermometers or thermistors and electrical resistance elements could be used but have limitations which will probably prevent extensive application in grain storages.

In many of the older upright storages, pipes are used in the stored grain to permit passage of a thermometer or thermocouple cable for determining grain temperatures at any depth. Most modern storages make use of insulated thermocouple wires wound on steel cables which are encased in an abrasion- and fumigant-resistant covering. These cables are permanently suspended from the bin roof and connected to a centrally located potentiometer where temperatures can be observed. For upright storages of from 15 to 20 feet in diameter, a single cable, having thermocouple junctions at 5- to 7-foot intervals along the cable, can be used to detect dangerous temperature conditions. Additional cables should be used when the storage diameter exceeds 20 feet.

In some flat storages probe thermometers are inserted at various locations and depths to determine grain temperatures. However, making a complete record of bulk temperature conditions in this manner is a time-consuming job. An indication of sudden increase in temperature may be missed unless thermometers are re-inserted at definite positions in the bulk. These objections can be avoided by using thermocouple cables. Small cables having thermocouple junctions at 3- or 4-foot intervals along the cable are suspended from the roof framing, or inserted into the grain after the bin is filled. If these cables are spaced not more than 20 feet apart critical temperature conditions in the deeper portions of the bulk can be detected. Detection of localized heating in the surface layers between the thermocouple cables may depend upon periodic inspection of the bulk surface.

High grain temperatures serve as a warning of possible damage from insects, microorganisms, or faulty aeration. Therefore temperature indicating equipment must be used regularly and the results recorded. When any abnormal rise in temperature is found, records should be made daily until corrective treatment has proved effective. If the grain is being aerated, temperatures should be recorded at least once a week until all of the bulk has reached the desired temperature.

COSTS OF AND POSSIBLE SAVINGS FROM AERATION SYSTEMS

COSTS OF OWNERSHIP AND OPERATION

Examples of actual equipment and installation costs of aeration systems in some of the typical off-farm grain storages in Texas and Kansas are shown in tables 5 to 7 respectively.

An example of the electric power costs incurred in the operation of an aeration system under specified conditions is shown in table 8.

Equipment and installation costs per bin of an aeration system for an upright storage bin for wheat at $\frac{1}{10}$ cfm per bushel is shown below. The sloping bottom bin is 16 feet in diameter and 94 feet high, and has a capacity of 15,000 bushels. These figures are based on cost information gathered in 1955 from an experimental installation in Georgia.

Type of aeration system	Aeration duct and supply pipe	Fan and motor	Electric wiring and starter	Automatic controls	Total cost per bin	Cost per bushel
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Cents*
Individual—1 fan for each bin	60	385	215	35	795	4.6

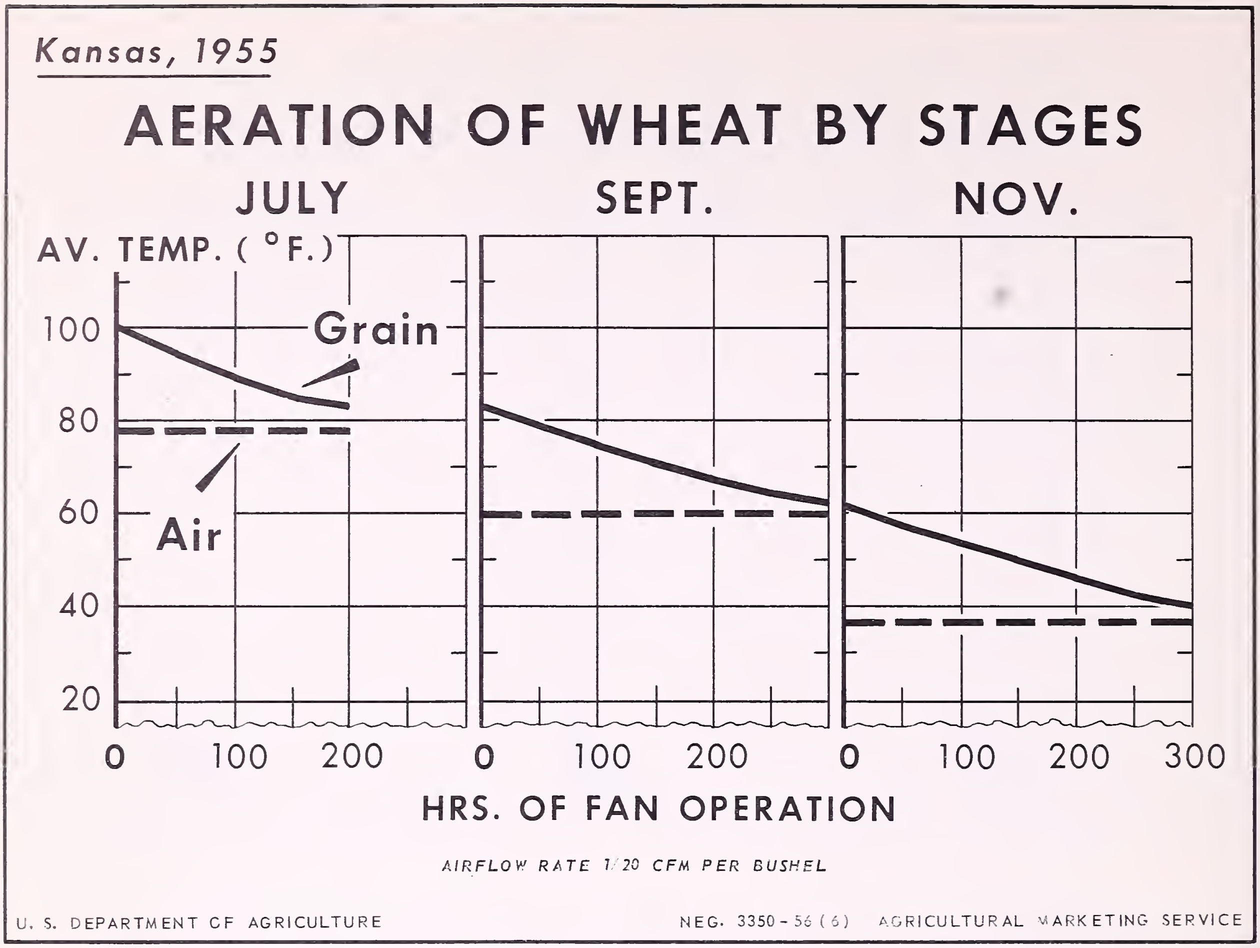

FIGURE 27.—Aeration of wheat by stages. The cooling period for the first stage was somewhat shorter than the following two stages. The moisture content of the wheat was reduced somewhat during the first stage. Apparently the cooling resulting from the evaporation of moisture increased the cooling rate.

TABLE 5.—*Equipment and installation costs of aeration systems for a 6-bin, upright storage for grain sorghum at an airflow rate of 1/10 cfm per bushel* [1]

[*Bin 22 feet diameter by 42 feet high; capacity 12,700 bushels; flat bottom*]

Type of aeration system	Equipment and installation costs							
	Aeration duct and supply pipe	Fan and motor	Electric wiring and magnetic starter	Automatic controls	Fumigation facilities	Total cost	Cost per bin	Cost per bushel
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Cents*
Individual—permanent connection for each bin. 1 fan for each of 6 bins	294	[2] 2340	750	42	480	3906	651	5. 1
Multiple—permanent connection for 6 bins. 1 fan for 6 bins	1670	[3] 815	256	42	271	3054	509	4. 0
Portable—portable connection for each bin. 1 fan for each 2 bins	294	[4] 1170	525	42	180	2211	368. 50	2. 9

[1] Based on cost information available from a commercial installation in Texas, 1955.
[2] 6–1 HP motors and fans. [3] 1–15 HP motor and fan. [4] 3–1 HP motors and fan.

Table 6.—*Equipment and installation costs of aeration systems for upright storages (wheat)* [1]

[*Bin 26 feet diameter by 100 feet high; 45,000 bushel capacity; flat bottom*]

Type of aeration system	Basic unit	Airflow rate	Equipment and installation costs					
			Aeration duct and supply pipe	Fan and motor	Electric wiring and controls	Total cost	Cost per bin	Cost per bushel
		c. f. m. per bu.	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Cents*
Permanent connection for each bin. 1 fan per bin	1 bin	1/20 for 1 bin	390	475	175	1, 040	1, 040	2. 3
Permanent connection for 4 bins. 1 fan per 4 bins	4 bins	1/40 for 4 bins	1, 675	535	325	2, 535	636	1. 4
Permanent connection for each 4 bins. 1 fan per 8 bins	8 bins	or 1/20 for 1 bin 1/40 for 4 bins	3, 300	575	450	4, 325	541	1. 2
Portable connection for each bin. 1 fan per 4 bins	4 bins	or 1/20 for 1 bin 1/20 for 1 bin	1, 520	575	350	2, 445	610	1. 4
Portable connection for each 2 bins. 1 fan per 8 bins	8 bins	1/20 for 2 bins	2, 975	625	450	4, 050	506	1. 1

[1] Based on cost information available from a limited number of commercial installations in Kansas, 1956.

Table 7.—*Equipment and installation costs of aeration systems for upright storages (wheat)* [1]

[*Bin 18 feet diameter by 100 feet high; 20,000 bushel storage capacity; hopper bottom*]

Type of aeration system	Basic unit	Airflow rate	Equipment and installation costs					
			Aeration duct and supply pipe	Fan and motor	Electric wiring and controls	Total cost	Cost per bin	Cost per bushel
		c. f. m. per bu.	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Cents*
Permanent connection for each bin. 1 fan per bin	1 bin	1/20 for 1 bin	380	395	175	950	950	4. 7
Permanent connection for 4 bins. 1 fan per 4 bins	4 bins	1/40 for 4 bins	1, 560	395	270	2, 225	556	2. 7
Permanent connection for 4 bins. 1 fan per 8 bins	8 bins	or 1/20 for 1 bin 1/40 for 4 bins	3, 120	425	400	3, 945	493	2. 4
Portable connection for each bin. 1 fan per 4 bins	4 bins	or 1/20 for 1 bin 1/20 for 1 bin	1, 440	425	300	2, 165	541	2. 7
Portable connection for 2 bins. 1 fan per 8 bins	8 bins	1/20 for 2 bins	2, 760	475	400	3, 635	457	2. 2

[1] Based on cost information available from a limited number of commercial installations in Kansas, 1956.

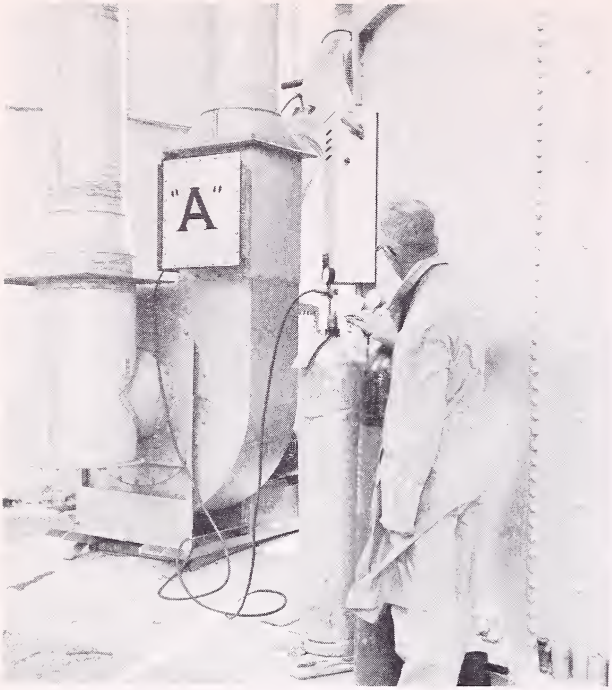

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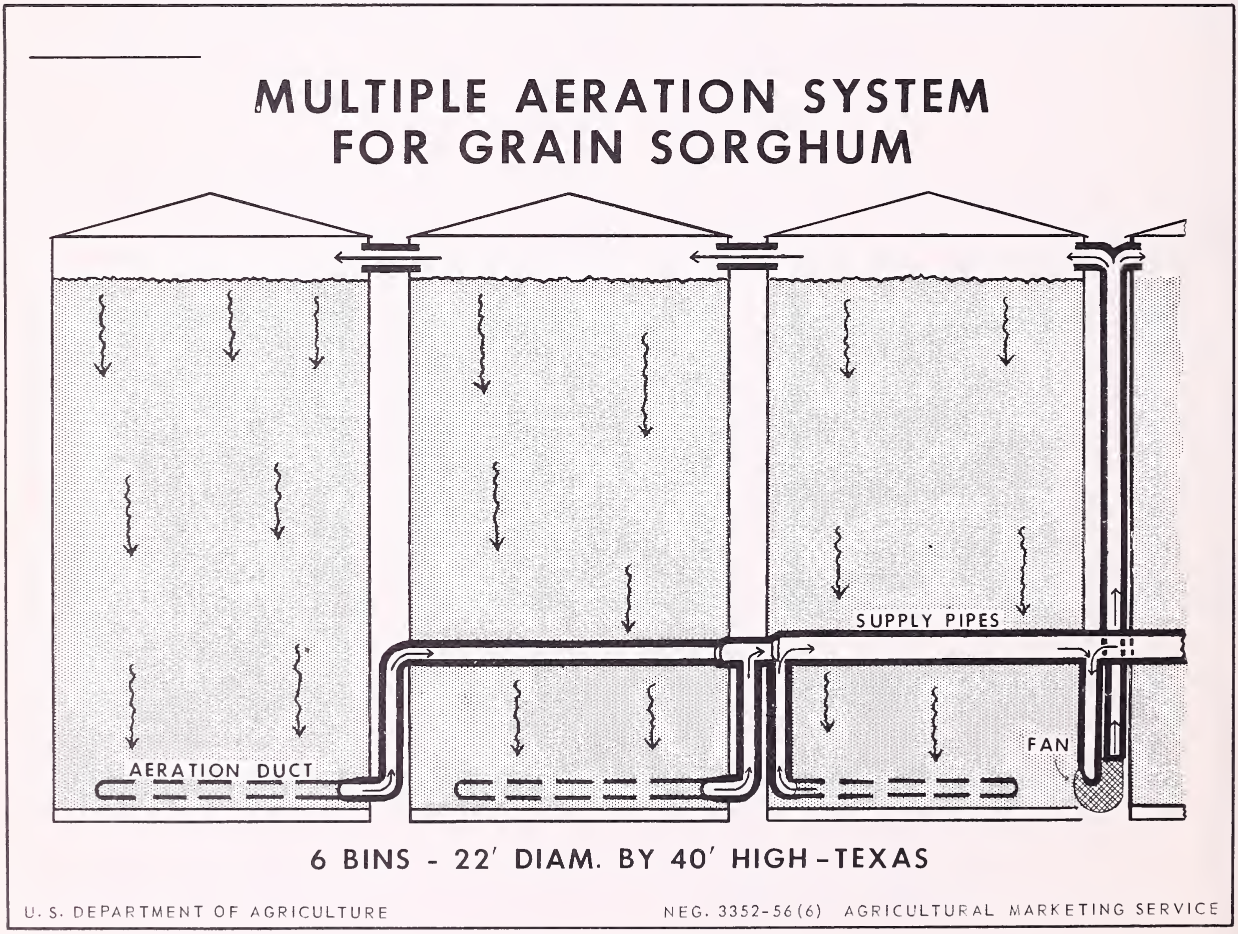
Figure 28 (A).—Introducing fumigant into an aeration system for fumigating stored grain. This is a closed system where fumigant is re-circulated through the grain. Plate "A" is removed during aeration.

(B).—The storages are connected by supply pipes near the top of each storage to permit the fumigant to be circulated and re-circulated through several bins with one fan (6 bins in this case).

B



Equipment and installation costs of an aeration system for a flat storage for dry pea beans, at an airflow rate of 1/10 cfm per bushel, are shown below. The storage is 100 feet long by 40 feet wide, 15 feet deep with a capacity of 48,000 bushels of grain. These figures are based on information furnished by a fan and equipment company, December 1956. Costs for the aeration duct and supply pipe include 184 feet of 21-inch diameter perforated circular aeration duct of 18-gage, galvanized and corrugated metal; and 24-inch diameter supply pipe with cutoffs, connecting tubes, and flashing. The fan and motor costs include an 18½-inch propeller fan and 1½ horsepower electric motor.

Type of aeration system	Aeration duct and supply pipe	Fan and motor	Electric wiring and starter	Automatic controls	Total cost	Cost per bushel
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Cents*
Individual—1 fan for each storage	1195	296. 25	148	50	1689. 25	3. 5

Table 8.—*Electric power costs incurred in the operation of aeration systems in upright wheat storages having a 100-foot grain depth, by specified cooling methods and airflow rates* [1]

Cooling method	Airflow rate	Electric power costs per bushel per year [2]
	cfm per bushel	*Cents*
Single stage	1/20	1/10
Three stages	1/20	1/4
Single stage	1/40	1/20
Three stages	1/40	1/10

[1] Data from experimental installations in Kansas.
[2] Based on power costs of 2 cents per kilowatt-hour.

COMPARISONS OF AERATION AND OF TURNING GRAIN ON STORAGE COSTS AND REVENUES

Adequate data for making cost comparisons of aeration and turning costs were not available for inclusion in this interim report. However, one large grain firm estimates that operating costs average 1/10 cent per bushel each time grain is turned. Other operators of flat and upright storages estimate these costs to range from 1/10 to ½ cent per bushel for each turn. Inquiries indicate that in some areas grain usually is turned an average of four times a year. On this basis operating costs would range from 4/10 to 2 cents per bushel per year for the four turns. To obtain total costs per bushel for turning grain, both equipment and ownership costs and costs from losses due to shrinkage and increases in dockage attributable to turning the grain must be added. Therefore the total annual cost for turning grain could range from ¾ to 3 cents per bushel. In comparison, available data indicate that the total annual cost for aerating stored grain ranges from ¼ to 1 cent per bushel.

Preliminary data on the comparative annual costs for aerating and for turning rice are shown in table 9. Turning rice four times per year, without turning through a drier, costs 2½ cents per barrel more than aeration. Turning the rice twice through a drier, with no heat added, costs about 5½ cents per barrel more than aeration.

In comparing the costs of turning and aerating grain, one item that should be taken into consideration is the practice of leaving at least one empty bin for turning grain. One installation in South Texas consisting of 5 steel upright storages, each having 25,700 bushel storage capacity, stored grain in 4 storages before aeration systems were installed. One empty storage received the turned grain. Aeration systems were installed in each of the five storages. Following the installation of the aeration systems, grain was stored in all 5 storages. This increased the total capacity by 25,700 bushels. At a storage rate of 1½ cents per bushel per month, the "additional" storage capacity increased the monthly revenue $385.50.

The cost of each aeration system was approximately $745.31. Using the "fifth bin" for storing grain paid for one aeration system in 2 months and for all 5 systems in 10 months.

The storage owner must consider several points in making a decision as to whether to install an aeration system. In general, if he now turns grain it should be practical to install aeration. However, if the grain is stored for only 1 to 3 months, and not turned, aeration may not pay. Or, if the storage is in an area where grain temperatures are not above 70° F. when stored, and where moisture migration and accumulation is not a factor during the winter months, aeration may not be needed. Aeration does not permit visual inspection of grain that is possible when it is turned. However, with available reliable grain temperature indicating equipment, it usually is possible to detect any indication of heating before deterioration occurs. Aeration also provides a practical and economical means of fumigating stored grain without moving it.

TABLE 9.—*Comparative annual ownership and operation costs for cooling 17,500 barrels (annual volume) of rice in upright storages by turning and aeration, Texas, 1956*

Method	Equipment	Initial cost	Expected life	Ownership costs: Depreciation	Ownership costs: Interest at 5 percent	Ownership costs: Insurance and taxes at 4 percent	Ownership costs: Total	Operating costs: Power and maintenance	Operating costs: Labor	Annual cost	Cost per barrel
		Dollars	*Years*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Cents*
1. *Aeration* [1]	1-fan and motor	1, 800	20	90. 00	45. 00	36. 00	171. 00	79. 70	[2] 26. 00	276. 70	1. 60
Total										276. 70	1. 60
2. *Turning four times.*[3]	1-bucket elevator	3, 000	20	60. 00	30. 00	48. 00	138. 00	10. 90		148. 90	0. 85
	1-tunnel conveyor	1, 600	15	42. 80	16. 00	25. 60	84. 40	7. 32		91. 72	0. 52
	1-gallery belt	1, 500	15	40. 00	15. 00	24. 00	79. 00	7. 32		86. 32	0. 50
									[4] 396. 00	396. 00	2. 26
Total										722. 94	4. 13
3. *Turning twice through drier* [5]	2-bucket elevators	6, 000	20	85. 80	42. 90	68. 40	197. 20	12. 48		175. 50	1. 00
	1-tunnel conveyor	1, 600	15	26. 67	10. 00	16. 00	52. 67	3. 66		56. 33	0. 31
	1-gallery belt	1, 500	15	25. 00	9. 38	15. 00	49. 38	3. 66		53. 04	0. 30
	1-drier	15, 000	20	247. 50	123. 75	198. 00	569. 25	64. 35		633. 60	3. 60
									[6] 316. 75	306. 00	1. 80
Total										1, 224. 47	7. 01

[1] Fan and motor used 100 percent of annual operating time in aerating rice.

[2] 1 man for 10 hours at $2.60 per hour.

[3] Bucket elevator, tunnel conveyor, and gallery belt used 40 percent of the total annual operating time in turning rice 4 times.

[4] 110 hours at $3.60 per hour (1 man at $2.60 per hour; one man at $1.00 per hour).

[5] 2 bucket elevators, 1 tunnel conveyor, 1 gallery belt used 25 percent and drier (with no heat) used 33 percent of the total annual operating time in turning rice 2 times through drier.

[6] 85 hours at $3.60 per hour (1 man at $2.60 per hour, one man at $1.00 per hour).

APPENDIX

INFORMATION AND CALCULATIONS FOR DESIGNING AN AERATION SYSTEM

Example—Wheat aeration system for an upright storage:

Design Steps	*Example*
I. Establish storage dimensions and capacity	One fan and one storage
A. Bin size—diameter and depth	18′ diameter—100′ depth
B. Bin capacity—Bushels:	
1. Floor area	$0.7854 \times (18)^2 = 254$ sq. ft.
2. Volume (cu. ft.) = floor area x depth	$254 \times 100 = 25{,}400$ cu. ft.
3. Capacity (bu.) = volume (cu. ft.) x 0.8 (1 cubic foot equals 0.8 bushel).	$25{,}400 \times 0.8 = 20{,}000$ bu.
II. Establish airflow rate and volume	
A. Select airflow rate (cfm/bu.) (table 1, p. 5)	$\frac{1}{20}$ cfm per bushel
B. Total volume (cfm) = total bu. x cfm per bu	$20{,}000 \times \frac{1}{20} = 1{,}000$ cfm
III. Determine aeration duct requirements (page 9)	
A. Total duct surface area (sq. ft.) $= \frac{\text{Air volume (cfm)}}{30 \text{ fpm}} = 33\frac{1}{3}$ sq. ft.	
B. Select aeration duct dimension:	
1. Select shape of duct	Round, perforated duct
2. Cross section size—diameter or dimension	Try 12-inch diameter
a. Surface area per foot of length (circumference).	3.14 sq. ft. per foot of length
NOTE. Effective surface area of round pipe in contact with floor, use 80 percent.	$3.14 \times 0.8 = 2.5$ sq. ft. per foot of length
3. Length required = total duct surface area ÷ surface area required per ft. of length.	$\frac{33.3}{2.5} = 13.3$ ft. minimun length needed for surface area
NOTE. Check bin size and clearance at drawoff.	
4. Select duct dimensions	Use 12-inch diameter and 14-foot length in 18-foot diameter bin
C. Check velocity within aeration duct	Maximum 2,000 fpm (page 9)
Velocity (fpm) $= \frac{\text{air volume (cfm)}}{\text{Cross sect. area (sq. ft.)}}$	$\frac{1{,}000}{0.54} = 1{,}850$ fpm
D. Aeration duct openings (page 9)	Recommendations for grain to be aerated
E. Strength of duct (page 9)	14-gage corrugated and perforated
IV. Determine supply pipe requirements (page 13)	
A. Cross section area based on maximum velocity of 2,500 fpm $= \frac{\text{air volume (cfm)}}{2{,}500}$	$\frac{1{,}000}{2{,}500} = 0.4$ square feet
9-inch minimum	Use 12-inch to match aeration duct.
V. Additional design factors for connection of several bins to a single fan (see IV)	Does not apply this example
VI. Opening for air entrance to bin	
A. Select opening with cross-sectional area twice that of supply pipe	Fill hole, window, etc.
B. Provide for continuous opening and protection from weather	
VII. Assemble fan requirements	
A. Airflow rate (II–A)	$\frac{1}{20}$ cfm per bushel
B. Total air volume (II–B)	1,000 cfm
VIII. Determine power and static pressure requirements.	Use chart in figure 18.
A. Static pressure	12.3 inches of water
B. Estimated power needed based on 0.21 HP per 1,000 bu. from chart in figure 18.	$0.21 \times 20 = 4.2$ HP

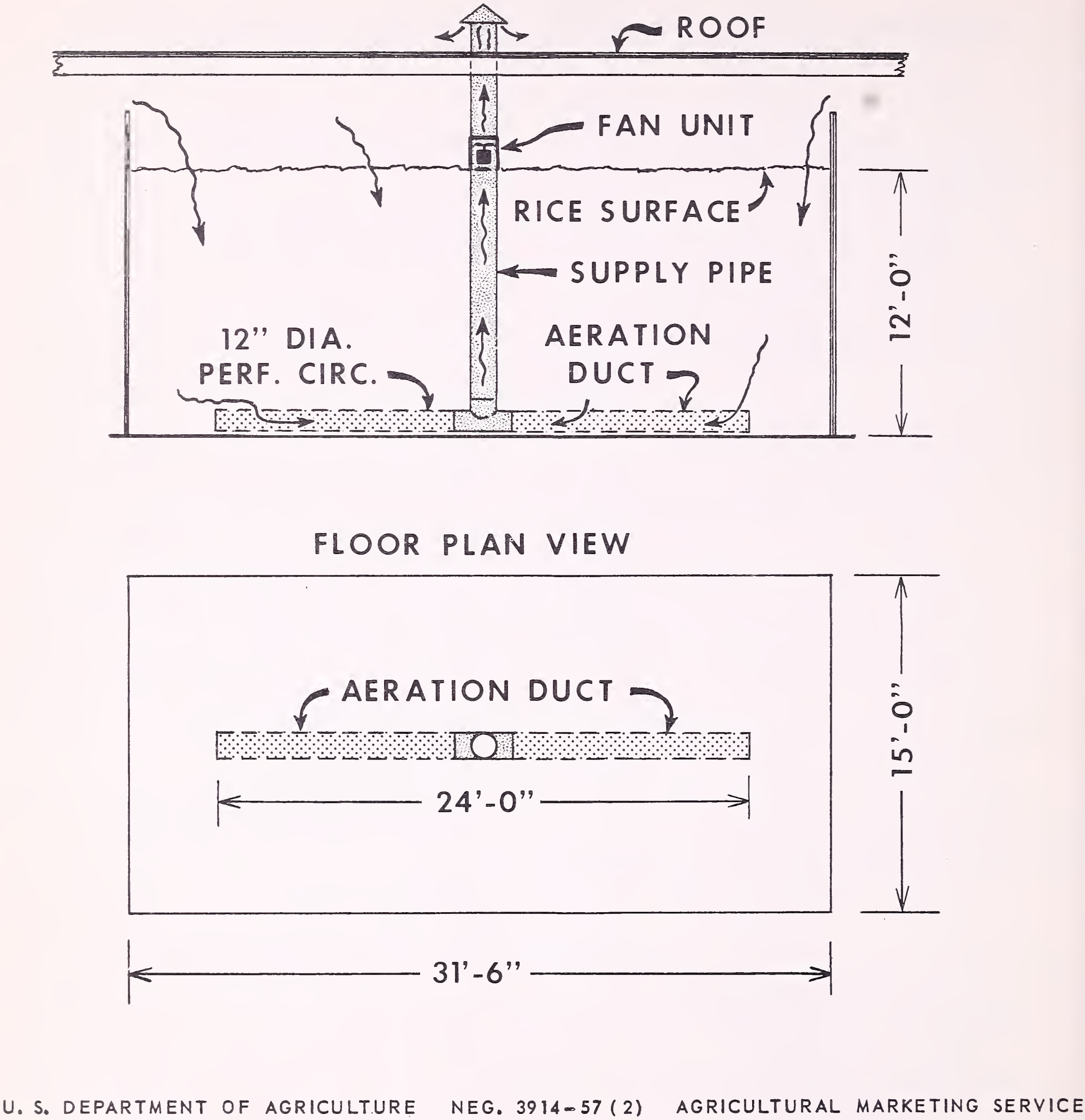


FIGURE 29.—Rice aeration system for flat storage. Rice bins were built inside an existing rice warehouse.

C. Select motor .... Use 5 HP electric motor

(Check with fan and motor supplier to determine if estimated power requirement is correct for the fan to be supplied.)

IX. Select controls

A. Automatic—temperature and humidity

B. Magnetic motor starter

C. Manual switch

Example—Rice aeration system designed for a flat storage:

I. Description of bin. A flat storage bin built inside an existing warehouse. Bin 15 feet by 31½ feet, of frame construction with corrugated sheet metal walls. Rice depth 12 feet. The capacity at a depth of 12 feet is approximately 1,267 barrels (4,560 bushels).

II. Desired features of aeration system. As indicated in table 1, recommended airflow rates in flat storages in southern areas are from 1/20 to ¼ cfm per bushel. The airflow rate for this storage was selected as ¾ cfm per barrel (⅕ cfm per bushel). The total air requirement then is about *950 cfm*. Other desired features are:

A. That the exhaust air from the rice be discharged outside the warehouse.

B. That the system be simple in construction and be portable so that when rice is not being stored the bin can be used for storing other materials.

C. That the system be easily converted to a closed system for fumigation.

D. That the system provide for the changing of direction of airflow through the rice.

The system was planned as shown in figure 29. By placing the fan as shown in the drawing the air is discharged out of the warehouse just above the roof. The construction and equipment are of such a nature that the parts are easily disconnected and moved. The system can be easily converted to a closed system by disconnecting the duct from the exhaust of the fan, raising the duct up and spreading an air-tight sheet over the top of the fan and the grain. The direction of air through the rice may be changed by disconnecting the fan and turning it over.

III. Aeration duct requirements

A. Duct spacing (page 13):

Following the general recommendations for duct spacing in flat storages the length of aeration duct needed was 24 feet

B. Duct surface area:

1. Required total surface area $\frac{950 \text{ cfm (I)}}{20 \text{ fpm (page 13)}} = 47.5$ square feet

2. Surface area per foot length of duct

Total surface area÷total length of duct $\frac{47.5 \text{ sq. ft.}}{24} = 1.98$ sq. ft.

3. A 12-inch diameter perforated circular duct was chosen. This duct was larger than required but further limited the static pressure against which the fan must work. As the duct was relatively short the added cost for the larger size was slight.

IV. Assemble fan requirements

A. Airflow rate (II) .... ¾ cfm per barrel

B. Total air volume .... 950 cfm

V. Power and static pressure requirements

Use chart in figure 19.

A. Static pressure .... 0.75 to 0.80 inch water

B. Estimated power needed .... ½ horsepower

C. Select motor. A tubeaxial fan which is rated to deliver 1,750 cfm at ½ inch, 1,000 cfm at ¾ inch or 600 cfm at one inch static pressure was chosen. A tubeaxial fan was chosen because it fitted into the duct without the use of transitions, it is lightweight, and it has a non-overloading characteristic which is desirable in the type of operation that is needed for this installation.

Data taken after the bin was loaded to a depth of 12 feet with rice showed the fan to be operating against 0.84 inch of water.

Example—Dry pea bean aeration system design for a flat storage.

I. Description of storage. A flat type metal building with continuous-arch construction forming walls and roof is to be used for the storage of pea beans. It is 100 feet in length and 40 feet in width. Pea beans will be stored to a depth of 15 feet. One fan and motor are to be used.

II. Establish storage capacity

A. Capacity (bushels):

1. Floor area—100 ft. x 40 ft.=4,000 sq. ft.

2. Volume (cu. ft.)=floor area x depth: 4,000 sq. ft. x 15=60,000 cu. ft.

3. Capacity (bu.)=volume (cu. ft.) x 0.8: 60,000 x 0.8=48,000 bu.

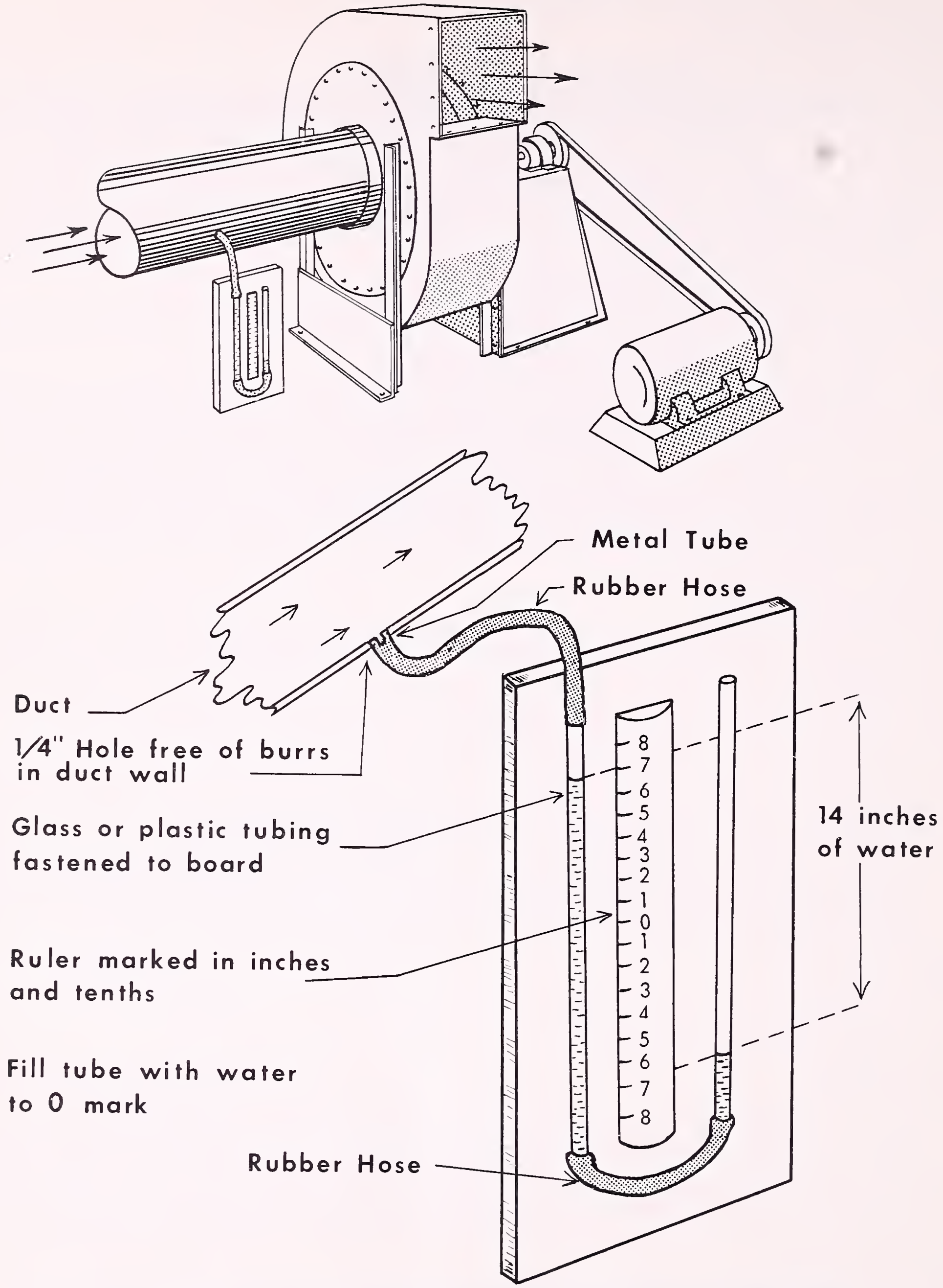


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Figure 30.—A U-tube pressure gage in use measuring the static pressure being exerted by a fan in pulling air from an aeration duct. The gage shows fan operating at a static pressure (suction) of 14 inches of water.

III. Establish airflow rate and volume

A. Select airflow rate (cfm/bu.), table 1—$\frac{1}{10}$ cfm per bushel

B. Total air volume (cfm) = total bu. x cfm per bu.: 48,000 bu. x $\frac{1}{10}$ cfm per bu. = 4,800 cfm

IV. Determine aeration duct requirements (page 13)

Two ducts, each 92 feet long, to extend lengthwise through storage and be spaced 15 feet apart (each duct 7½ feet from centerline of storage). (Note: Natural cooling will occur next to outside walls so ducts can be placed closer to center of storage). Round perforated ducts selected. Supply pipe is to connect two ducts together outside storage with air to be exhausted by one fan.

A. Volume of air to be handled by each duct.

Total air volume ÷ number of ducts: $\frac{4{,}800\text{ cfm}}{2\text{ ducts}} = 2{,}400$ cfm per duct

B. Determination of size of duct (page 9):

Maximum permissible velocity of air in duct = 1,000 fpm. Therefore, $\frac{2400\text{ cfm}}{1000\text{ fpm}}$ (airflow required) = 2.40 sq. ft. minimum cross sectional area of each duct.

21-inch duct selected (2.4 sq. ft. in cross sectional area).

C. Check duct size to determine if surface area is adequate (page 13):

20 fpm = air velocity selected for the duct surface area

$\frac{2400\text{ cfm/duct}}{20\text{ fpm}} = 120$ square feet of surface area required per duct.

For circular ducts on floor, 80 percent of surface area effective.

$\frac{120\text{ sq. ft.}}{.80} = 150$ square feet = total surface area required.

$\frac{150\text{ sq. ft.}}{92\text{ ft. length}} = 1.63$ square feet of surface area/feet of length.

However, 21-inch duct = 5.4 square feet per foot of length, adequate surface area.

V. Determination of supply pipe size (refer to page 13)

1,500 fpm = selected velocity in supply pipe.

$\frac{4{,}800\text{ cfm}}{1{,}500\text{ fpm}} = 3.2$ square feet = cross sectional area required per duct.

24-inch supply duct selected (3.14 square feet area)

VI. Assemble fan requirements

A. Airflow rate -- $\frac{1}{10}$ cfm per bushel

B. Total air volume -- 4,800 cfm

VII. Determination of power and static pressure requirements. Use chart in figure 22.

A. Static pressure = 0.4 inches of water.

B. Estimation of power required:

1. From figure 22, 0.011 horsepower per 1,000 bushels are required.
2. Total horsepower = 0.011 x $\frac{48{,}000\text{ bushesl}}{1{,}000} = 0.53$ horsepower.

C. Select ¾ horsepower motor to move 4,800 cfm at 0.4-inch static pressure.

Note: In actual practice, it may not be possible to obtain a fan and motor to meet these requirements and yet be convenient to attach to a 24-inch diameter supply pipe. It is likely that a 1 to 1½ horsepower motor will be required.

VIII. Cost of system—See page 37.

STATIC PRESSURE MEASUREMENTS

Various instruments are employed for measuring static pressures. The *U tube* is probably the simplest and most common of the self-indicating pressure gages or manometers (fig. 30). The U-tube is a glass or plastic tube partially filled with water. The static pressure is read directly in inches of water by reading the difference in the levels of water of the two sides. The bore of the tube should be $\frac{3}{16}$ to ¼ inch in diameter and the walls perfectly clean. In general, the U-tube should be located level with the desired point of pressure observation. Otherwise, a significant error may result from the weight of the column of fluid in the connecting tube.

The "pressure tap" or connection may be a small hole, from $\frac{1}{16}$ to ¼ inch in diameter, drilled in the side of the supply pipe. A tube is used to make a connection between the pressure tap and the U–tube.

The U-tube (fig. 30) is simple to build and is satisfactory for making static pressure readings for checking the performance of a fan on an aeration system. Similar pressure gages also can be purchased.

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